Guidance Document for Implementing On/Off Aeration in Municipal Sewage Treatment Plants (Liquid Treatment Train)

March 2000

Ontario

Ministry of the Environment

Guidance Document for Implementing On/Off Aeration in Municipal Sewage Treatment Plants (Liquid Treatment Train)

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Industry Conservation Branch
Ministry of the Environment (MOE)

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1 Introduction

1.1 Background

Most existing sewage treatment plants (STPs) were designed with excess capacity to meet future needs and are currently operating below designed capacity. This often results in plants nitrifying even if they were not designed for nitrification. Nitrification is the biological oxidation of ammonia to nitrate. Depending on effluent pH, ammonia can be toxic to fish whereas nitrate is non-toxic at levels that would normally be found in municipal sewage effluent. However, nitrification increases oxygen consumption and aeration energy costs by 100% or more in comparison to non-nitrifying plants. In order to recover some energy costs and improve effluent quality at nitrifying STPs, denitrification is often considered. Denitrification often improves sludge settling characteristics and eliminates the possibility of rising sludge in the final clarifier (see Section 2.2.1 for more details). Denitrification is the biological removal of organic pollutants using nitrate in the absence of oxygen. This reduces the oxygen required to remove organic pollutants and results in significant energy savings and reduced nitrogen (nutrient) loading to the receiver.

In 1993, a study by Environment Canada's Wastewater Technology Centre identified on/off aeration as an innovative low-cost approach for achieving both nitrification and denitrification in existing STPs. The approach involves cycling the aerators on and off to achieve nitrification during the ON cycle and denitrification during the OFF cycle. Subsequently, Environment Canada's Great Lakes 2000 Cleanup Fund (GL2000CuF) and the Ontario Ministry of the Environment (MOE) co-sponsored a full-scale demonstration of on/off aeration at the Tillsonburg STP during 1995/96. The study demonstrated over 20% aeration savings and up to 60% total nitrogen (TN) reduction in the final effluent compared to continuous aeration.

As a result, GL2000CuF and MOE co-sponsored another study to implement and evaluate on/off aeration at 4-6 STPs in Ontario with different types of aeration systems and process configurations. The main objective of this study was *to develop a guidance document with screening and design tools for implementing and optimizing on/off aeration at other municipal STPs.* This guidance document, which also includes case studies of the candidate plants, was developed to meet this objective.

In the fall/winter 1997, on/off aeration was implemented at four STPs in Ontario (Cobourg #2, Deseronto, Elmvale and Paris). These plants were evaluated and optimized over a 12 months period and the results were compared to the previous 12 months periods when the plants were operated in continuous aeration mode. The approach used in this project was to integrate proper process control (sludge mass control) with the implementation of on/off aeration operation. This is because proper sludge mass control is essential for achieving consistent effluent quality and

on/off aeration must be implemented within the context of good overall process control to realize the benefits while ensuring that effluent quality is maintained or improved.

1.2 Purpose and Outline of this Document

This document is intended to provide guidance for implementing on/off aeration at municipal sewage treatment plants to improve effluent quality and reduce operating costs. Improved effluent quality is achieved by reducing total nitrogen concentration and suspended solids concentration in the plants which have poor sludge settlability. Lower operating cost is achieved through aeration energy savings. On/Off aeration control has been successfully applied in aerobic digesters in some plants outside of Ontario to reduce energy costs and improve biosolids and digester supernatant characteristics. A detailed literature review on this subject is provided in separate report entitled "**Application of On/ Off Aeration to Aerobic Digestion – A Literature Review**"

This document includes:

- screening tools for assessing STPs to determine whether they are suitable candidates for on/off aeration. It also includes techniques for conducting trials and implementing on/off aeration, and methodologies for assessing and optimizing the technology over the long term.

- As a preamble to the screening and implementation techniques for on/off aeration, a general overview of nitrification, denitrification and on/off aeration is described in Section 2.

- Section 3 provides a summary of the results from the evaluation at the four participating plants.

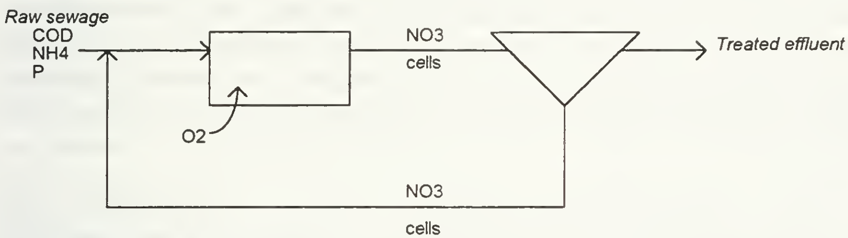
- The implementation and detailed results for each participating plant are described in Appendix A.

- Information Sheets useful for screening plants for On/Off aeration trials are provided in Appendix B.

2 Overview of Nitrification, Denitrification and On/Off Aeration

2.1 What is nitrification?

Figure 2-1 illustrates the main elements of the nitrification process. Nitrification is the biological conversion of ammonia (NH_4^+) to nitrate (NO_3^-) that can occur in the aeration tank of an activated sludge process, provided the proper conditions are present. The conditions required to achieve nitrification are discussed in the next section. In this section, the most significant impacts of nitrification are summarized.



Biochemical Reaction

- Nitrifying bacteria convert NH_4 to NO_3 under aerobic condition

$$\boxed{NH_4^+ + O_2 + \text{Alkalinity} \Rightarrow NO_3 + \text{Cells} + H_2O}$$

Figure 2-1 Conceptual illustration of nitrification

2.1.1 What are the Impacts of Nitrification?

Nitrification will eliminate the effluent toxicity due to ammonia. Residual chlorine and ammonia are the principal causes of acute toxicity of effluents from municipal sewage treatment plants (STPs). It has been proposed that ammonia concentration limits of 4 mg/L or less are required to consistently achieve a non-toxic effluent at the end of the discharge pipe. To reduce municipal effluent ammonia concentrations to this level, treatment plants must nitrify.

Nitrification results in significant additional oxygen demand. The oxygen requirement for nitrification is 4.6 kg O_2 per kg of ammonia nitrogen. Depending on the relative concentrations of carbonaceous material (which may be expressed as BOD_5 or COD) and ammonia in the untreated wastewater, nitrification could result in an increased oxygen demand of 100% or more.

Nitrification consumes significant alkalinity and affects plant capacity. The nitrification reactions consume about 7.1 kg of alkalinity expressed as $CaCO_3$ per kg of ammonia nitrogen nitrified. Loss of alkalinity can cause significant drops and fluctuations in pH and as a result, decrease in nitrification rate. Nitrifiers grow much more slowly than heterotrophs (i.e. the BOD consuming organisms). Because nitrifiers grow relatively slowly, nitrifying wastewater treatment plants must be operated at a longer solids retention time (SRT) than non-nitrifying plants. This can impact the capacity of the treatment plant because a longer SRT will result in a higher operating mixed liquor solids concentration and higher clarifier solids loading rates. To maintain mixed liquor solids concentration and clarifier solids loading rates within critical values, the aeration tanks and final clarifiers have to be expanded or the capacity of the plant has to be de-rated. Sometimes a longer SRT will also contribute to foaming and sludge bulking problems.

Denitrification can occur in the secondary clarifiers. Denitrification is the biological conversion of nitrate (NO_3^-) to nitrogen gas (N_2). Although this is the process that is being utilized advantageously in on/off aeration and other biological nutrient removal processes, if can also occur unintentionally in the secondary clarifiers of a nitrifying plant. The resulting nitrogen gas bubbles can cause solids to rise to the surface and negatively impact effluent quality.

2.1.2 How to Operate a Plant to Achieve Nitrification?

The previous section indicated that there are three crucial factors for nitrification. These factors are listed and discussed below.

There must be sufficient aeration capacity Nitrification will result in additional oxygen demand. Also, the growth rate of nitrifiers is more sensitive to low dissolved oxygen concentrations. Although somewhat site specific, a requirement for a dissolved oxygen concentration greater than or equal to **2 mg/L** can serve as a general guideline.

Sufficient alkalinity must be present in the influent A typical Ontario municipal wastewater will require 200 to 250 mg $CaCO_3$ alkalinity per litre in the influent for nitrification

to occur effectively. In areas where the wastewater is weakly buffered, supplemental alkalinity may need to be added in the form of lime or caustic.

A nitrifying treatment plant may require a longer SRT The conceptual definition of the SRT required for nitrification is shown in **Figure 2-2.** This definition shows that the SRT required for nitrification depends on the growth rate of the nitrifiers which can vary significantly between treatment plants. It has often been suggested that a lower nitrifier growth rate can be expected at treatment plants with more industrial wastewater input. The growth rate, and thus the required SRT, is also sensitive to temperature. The nitrifier growth rate decreases by about 10% for every drop in temperature of 1°C. **Figure 2-3** shows a typical variation of the required SRT with temperature.

Nitrifying plants must carefully monitor and control sludge inventory Because of the sensitivity of nitrification to SRT, SRT control should be part of the normal operation of a nitrifying treatment plant. Equally important, operators must have a good knowledge and control of the mass of sludge in the secondary clarifiers. Minimizing the mass in the clarifiers reduces the possibility of rising sludge and reduces the total SRT required. An effective sludge disposal program is another important factor in overall sludge inventory control. Restrictions on the ability of a plant to remove and dispose of waste sludge can impact on an operator's ability to control the SRT at suitable levels. Plants which cannot remove and dispose waste sludge effectively would have to carry excessive solids in their aeration tanks and final clarifiers. This can result in mixed liquor solids being washed out in the final effluent during high flows.

SRT Requirement for Nitrification

Minimum SRT required for nitrification	=	minimum time required for a nitrifying bacterium to reproduce and replace itself

If SRT > min SRT	⟹	nitrifying organisms will grow and accumulate in mixed liquor to a steady state level

Figure 2-2 Definition of the minimum SRT required for nitrification.

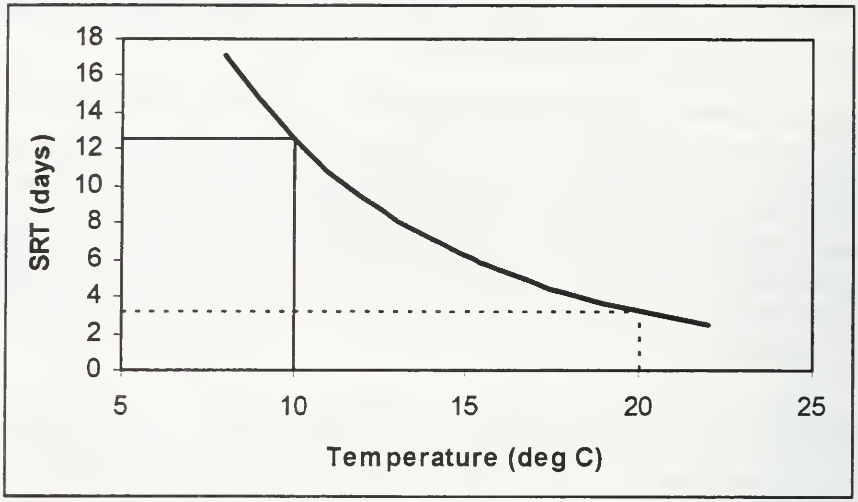


Figure 2-3 Typical variation with temperature of minimum SRT required for nitrification.

2.2 What is denitrification?

Figure 2-4 is a conceptual illustration of denitrification in an activated sludge process. In the absence of dissolved oxygen, certain heterotrophic bacteria (denitrifiers) use nitrates and nitrites (NO_x^-) in place of oxygen to oxidize carbon. The denitrifiers convert the NO_x^- to N_2 gas. The condition in which dissolved oxygen is absent but NO_x^- is present is termed anoxic. The most significant impacts of denitrification in a wastewater treatment plant are summarized below.

2.2.1 What are the Impacts of Denitrification?

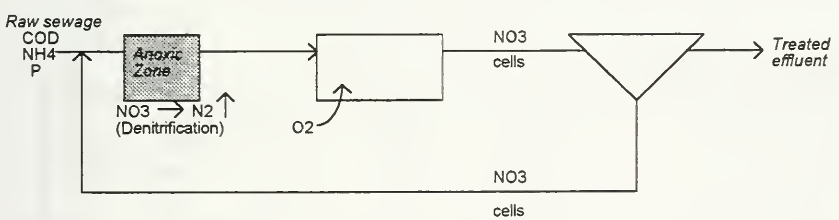
Denitrification can result in improved effluent quality Nitrification results in the conversion of nitrogen from one soluble form (ammonia) to another (nitrates). With denitrification, the nitrogen is removed completely in the form of nitrogen gas. As a result, the total nitrogen concentration in the effluent is reduced, which reduces the nutrient loading to the receiving stream.

A portion of the oxygen used in nitrification is recovered through denitrification For every kg of nitrate nitrogen used to oxidize the carbonaceous material in the wastewater, the O_2

requirement decreases by 2.86 kg. The resulting reduction in total oxygen demand can be greater than 20%.

Denitrification results in a recovery of alkalinity Every kg of nitrate nitrogen used for denitrification results in a recovery of 3.6 kg of $CaCO_3$ alkalinity. In other words, about 50% of the alkalinity consumed in nitrification is recovered through denitrification.

By denitrifying in the aeration basin, secondary clarifier performance can be improved There are two principal reasons for this. First, if the concentration of nitrate nitrogen leaving the aeration tank and entering the clarifier is reduced, there is less potential for generation of nitrogen gas in the clarifier. As a result, there is less potential for rising and floating sludge. Second, many of the filamentous organisms responsible for foaming and bulking sludge thrive under aerobic conditions only. Although the impact will be site specific, it is possible that if a portion of the aeration tank is anoxic, the growth of floc-forming organisms will be favored over filamentous organisms.



Biochemical Reaction

- **NO_3 is utilized in place of O_2 for BOD removal under anoxic conditions**

$$\boxed{NO_3 + BOD \rightarrow N_2 + Cells + H_2O + CO_2}$$

Figure 2-4 Conceptual illustration of denitrification in an activated sludge process.

2.2.2 How to Achieve Denitrification in a Municipal Treatment Plant?

For appreciable denitrification to occur, nitrate nitrogen and readily biodegradable carbonaceous material must both be available at the same point in the process. **Figure 2-5** shows two simple ways of achieving this objective. The first option is to install baffles in the aeration tank to create a separate dedicated anoxic zone in which a mixer is installed and the air is turned off. **Figure 2-5** shows a typical configuration where 25% of the aeration tank volume is anoxic and 75% is aerobic. Depending on whether sufficient nitrate can be provided by the return activated sludge stream, a recycle from the "tail end" of the aerobic zone to the anoxic zone may be required in some plants. A second simple option is to cycle the air on and off in the entire tank, thereby creating an "on/off aeration process". **Figure 2-5** illustrates a system where for a given fixed total "on/off" cycle time, the air will be on for 75% of the cycle and off for 25% of the cycle.

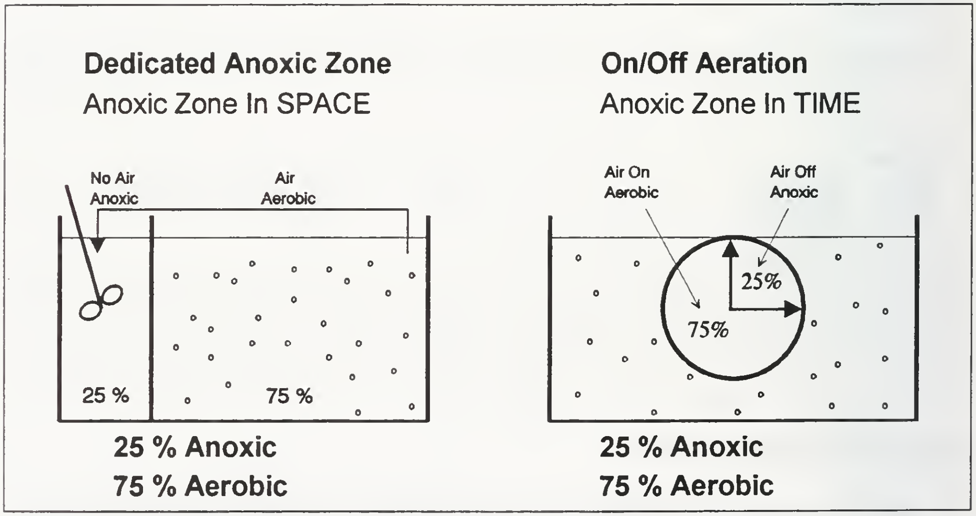


Figure 2-5 Dedicated anoxic zones vs. on/off aeration for denitrification.

2.3 Advantages of On/Off Aeration Process for Denitrification.

The following are some of the advantages of utilizing on/off aeration to achieve denitrification in a nitrifying activated sludge plant:

- The benefits of denitrification (energy savings, improved sludge settleability, etc.) can be realized by implementing only operational changes and minor, low-cost equipment modifications.
- The process has greater flexibility for adjusting the anoxic and aerobic hydraulic retention times (HRTs) than processes incorporating dedicated anoxic zones. The relative anoxic and aerobic HRTs can be adjusted by changing the aerator cycle time. On/off aeration can be temporarily suspended when the plant experiences difficulties in maintaining nitrification due to heavy industrial loads, cold temperature and/or high flows.
- Total aeration energy savings may be higher than the savings due to turning the aerators off for a portion of the time. On/off aeration may also improve oxygen transfer efficiency due to the higher oxygen transfer driving force at the end of the air-off/ beginning of the air-on period.
- Activated sludge basins which are difficult and expensive to retrofit through baffling, may be able to incorporate on/off aeration. For example, a square basin with surface aerators would require a significant amount of reconfiguration to incorporate dedicated anoxic zones. However, on/off aeration could be incorporated simply by installing a timer on the surface aerators.
- On/off aeration can be installed quickly and realize immediate benefits. Retrofits such as a mixed liquor recycle can be added later to improve total nitrogen removal.
- On/off aeration can be combined with a biological nitrogen removal configuration using dedicated anoxic zones to increase the flexibility of the plant. For example, the aerobic HRT can be increased in a plant incorporating a single anoxic zone by cycling aerators on and off in that zone.

In summary, on/off aeration is a simple approach for achieving the benefits of denitrification in a nitrifying treatment process. A more detailed discussion of the implementation of this approach is provided later in the document. However, the following simulated example provides a simple illustration of the process impacts of on/off aeration.

2.3.1 On/Off Aeration Simulation Case #1: Illustration of Continuous vs. On/Off Aeration

This section presents a simulated example to illustrate the impact of on/off aeration. Key design and operating conditions for the example plant are shown in **Table 2-1**. A simple activated sludge layout was set up in the BioWin wastewater treatment process simulator (**Figure 2-6**).

Table 2-1 Design and operating parameters for on/off aeration simulation

Influent Flow	
Average Daily Flow (ADF)	10,000 m^3/day
Bioreactor	
Volume = 5,000 m^3	Hydraulic Retention Time (HRT) = 12 hours at ADF
Final Clarifier	
Area = 500 m^2	Surface overflow rate (SOR) = 20 $m^3/m^2/d$ at ADF
Sludge Wastage Rate	200 m^3/day
Solids Retention Time (SRT)	12.5 days
Air Supply Rate	2.5 m^3/s

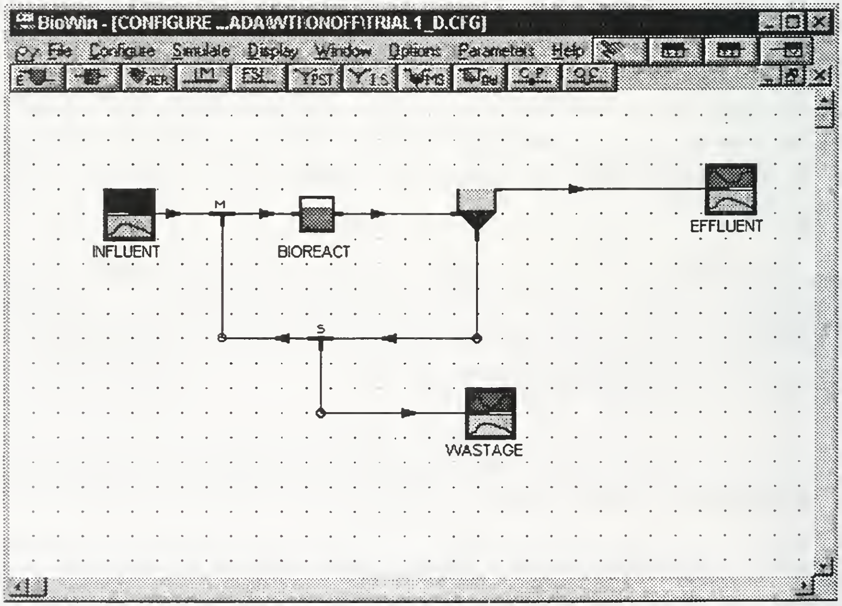


Figure 2-6 Activated sludge layout used in the BioWin simulator to illustrate on/off aeration.

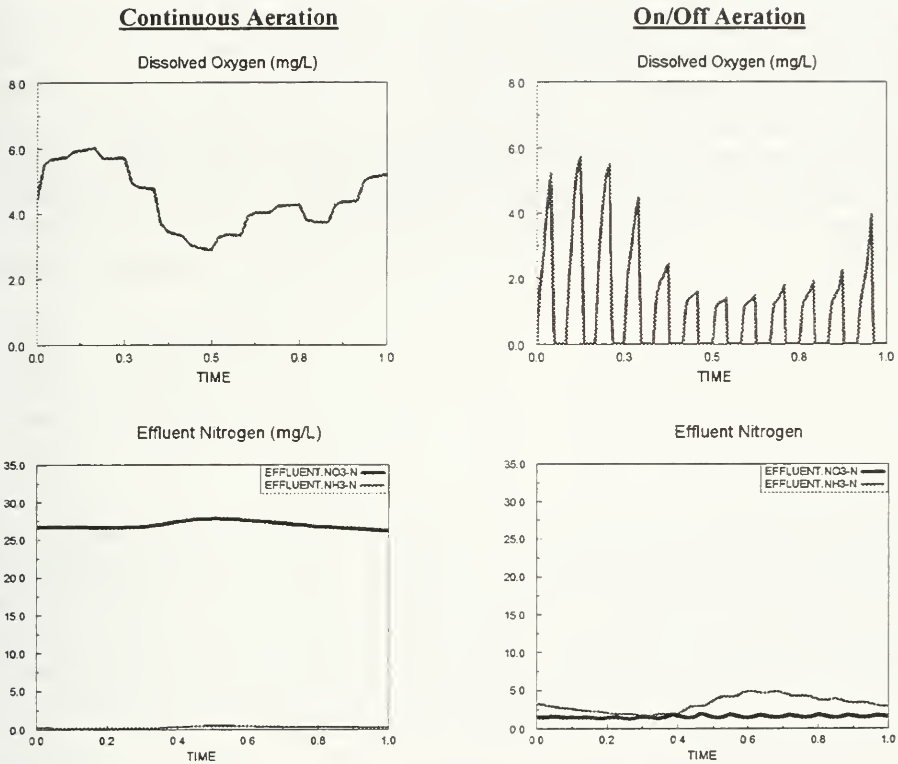


Figure 2-7 Results of simulations of continuous vs. on/off aeration (*time in units of day*)

The results of simulations showing the diurnal pattern for two cases are shown in Error! Reference source not found.. In the first case, the plant was simulated using a continuous air supply rate (2.5 m^3/s). The simulation results show that the plant was nitrifying completely. The effluent ammonia and nitrate concentrations throughout the day were less than 1 mg/L and greater than 25 mg/L, respectively. In the second case, for a repeated on/off cycle of 2 hours, the air was on for 1 hour (at 2.5 m^3/s) and off for 1 hour. The resulting dissolved oxygen response illustrates the pattern of aerobic and anoxic periods in the aeration tank. The effluent results show the dramatic impact of this operating mode. The average effluent nitrate concentration

decreased to about 2 mg/L. Although there was some increase in the effluent ammonia concentration, the average ammonia was less then 4 mg/L. The effluent ammonia peaked at around 5 mg/L. The reason for this peak was that the dissolved oxygen concentration during the peak loading time of the day did not reach 2 mg/L during the air on phase. This problem could be addressed by increasing the air on portion of the cycle during the peak time of the day. More discussion on the optimization of on/off aeration is included in Section 4 of this document. However, these results provide one note of caution in the implementation of this process – on/off aeration impacts the nitrification rates at the plant and must be implemented with a strong understanding of the interactions between SRT and nitrification, and dissolved oxygen levels and nitrification.

3 Summary of Case Studies

In the spring of 1997, five municipal sewage treatment plants in Ontario were selected to participate in the on/off aeration study. The plants were selected to include typical small to medium size STPs in Ontario. Their sizes ranged from 1,400 – 11,700 m^3/d and their current operating capacity ranged from 50 – 93 % of design capacity. The plants have different types of aeration systems and process configurations. One of the plants was dropped at the beginning of the study because of technical and operational issues at the plant. The remaining four plants participated in the study by implementing on/off aeration and sludge mass control during 1997/98. Case studies of the following plants are described in **Appendix A** and a summary of the results is presented in this section:

- Case 1 Cobourg #2 STP
- Case 2 Deseronto STP
- Case 3 Elmvale STP
- Case 4 Paris STP

Prior to implementing on/off aeration, operators from the participating plants and other interested plants attended technology transfer workshops on sludge mass control and on/off aeration operation. In addition, on-site training and technical support were provided to operators of the four participating plants throughout 1997/98. The workshops and training focused on implementing on/off aeration and sludge mass control for improving overall plant performance (i.e., improving effluent quality and reducing operating costs).

Following the implementation of SRT control and on/off aeration at the participating plants, the operating conditions and plant performance were monitored and optimized over 6 – 12 months periods. Operating conditions and results from the four plants are summarized in **Table 3-1** and a brief description for each plant is given below:

- *Cobourg #2 STP* is a conventional activated sludge plant with a design capacity of 11,700 m^3/d and current ADF of 5,900 m^3/d (50% design capacity). The plant consists of two parallel trains with one aeration tank per train. Aeration is provided by mechanical surface aerators: a 2-speed 20/30 Hp aerator in aeration tank 1 and a 60 Hp variable speed aerator in aeration tank 2. Prior to starting on/off aeration, a SRT control program was set-up in July 1997. The plant aeration control software was modified during this period 1998 to allow cycling of the aerators. The flow split to the aeration tanks was also changed from 50/50 to 35/65 for tank 1/tank2 to better utilize the capacity of the aerators in each tank. On/off aeration was implemented in September 1997 by alternately cycling the aerators 30 min

on/30 min off. During the off cycle the aerator in tank 1 shut off completely and mixing is provided by residual turbulence in the tank, while in tank 2 the aerator is operated at a very slow speed to provide active mixing. Process performance was closely monitored between October 1997 and September 1998. The results in **Table 3-1** show that on/off aeration had virtually no impact on the effluent concentrations of the conventional parameters (BOD, TSS and TP). However, the effluent total ammonia-N concentration was reduced significantly due to consistent SRT control. The effluent total-N concentration reduced modestly and the total plant energy cost reduced by about 6% ($4,000 annually) due mainly to on/off aeration. Retrofit cost for this plant was less than $1,000.

- <u>Deseronto STP</u> is a donut type extended aeration package plant with a design capacity of 1,400 m^3/d and current ADF of 1,300m^3/d (93% design capacity). The plant is equipped with fine bubble membrane diffusers and variable speed positive displacement blowers (only one is used at a time). A SRT control program was implemented in September 1997. The plant was retrofitted in October by installing a programmable electronic timer to allow cycling of the blowers. Mixing during the air off cycle was provided by residual turbulence and the influent flow. On/off aeration was initiated in November by cycling the blower 30 min on/30 min off during the day and 30 min on/45 min off during the night. Process performance was closely monitored between October 1997 and September 1998. The results show that on/off aeration had virtually no impact on the effluent concentrations of the conventional parameters (BOD, TSS and TP). During the winter months, the monthly average total ammonia-N concentration in the final effluent increased from less than 2 mg/L to over 12 mg/L due to the loss of nitrification. The main reason for losing nitrification during the winter was because the plant staff lowered the SRT from between 20-40 days to less than 20 days because the plant was experiencing some sludge handling problems. The annual average effluent total-N concentration was unchanged because of the increased ammonia-N concentration during the winter months. The total plant energy cost was reduced by approximately 21% ($3500 annually) due to on/off aeration. Retrofit cost for this plant was $2,700.

- <u>Elmvale STP</u> is an extended aeration plant with a rated design capacity of 1,500 m^3/d and current average daily flow of 1,100 m^3/d (73% rated design capacity). This corresponds to an average HRT of 42 h based on the combined volume of the two aeration tanks. Since the plant receives primarily residential wastewater, it appears that the plant is significantly underrated at 1,500 m^3/d. Aeration is provided by a jet aeration system and the air is supplied by positive displacement blowers. Prior to this study, the plant installed a common air header to connect the blowers for the aerobic digester with blowers for the aeration tanks, re-wounded one 50 HP blower with a double coil, and took one aeration tank out of service to reduce the average HRT to about 21 hours. These retrofits were done between January and

July 1997 to improve the overall energy efficiency in the plant. A SRT control program was initiated in September 1997, one month after on/off aeration was implemented in August. A mechanical timer was used to cycle the blower between on/off modes. The jet pumps provided mixing during the air off cycle. Initially, the blower was cycled 30 min on/30 min off and was later optimized to 45 min on/75 min off during AM hours and 60 min on/60 min off during PM hours. The blower output capacity was also reduced from 75% to 50% by changing the pulley. Process performance was closely monitored between August 1997 and July 1998. The results show that on/off aeration had virtually no impact on the effluent concentrations of the conventional parameters (BOD, TSS and TP) and total ammonia-N. The effluent total-N concentration was reduced significant and the plant achieved about 45% ($27,000 annually) reduction in the total plant energy cost. The energy savings are due to the combination of the changes made at the plant prior to and as part of implementing on/off aeration. Total retrofit cost for this plant was $8,000.

- *Paris STP* is an extended aeration with a design capacity of 7,100 m^3/d and current ADF of 3,600 m^3/d (51% design capacity). The plant consists of two parallel trains, with each train consisting of two aeration tanks and two final clarifiers. Each of the four aeration tanks has one 25 HP mechanical surface aerator and the aerators are equipped with mechanical timers. A SRT control was implemented in the fall of 1997 for two to three months prior to starting on/off aeration control. Soft-start switches were installed on the aerators to reduce the impacts of frequent re-starts during on/off aeration. On/off aeration was initiated in February 1998 by alternately cycling the aerators in the first tank of each train using 30 min on/30 min off cycle times. Process performance was monitored for a eight month period between February and July 1998. The results show that on/off aeration had virtually no impact on the effluent concentrations of the conventional parameters (BOD, TSS and TP). However the average effluent total ammonia-N concentration increased significant due to the loss of nitrification during the winter months. This was due to a significant increased in industrial organic loading to the plant which resulted in limiting DO conditions in the aeration tanks for effective nitrification. As a result of this on/off aeration was suspended after about six months of operation. The total plant energy cost during the six months period compared to the corresponding period from the previous year showed 13 % reduction due to on/off aeration. This was projected to be $5,600 annually if on-/off-aeration can be maintained year-round. Retrofit cost (for buying and installing the four soft-starters) was $8,200.

The results show that on/off aeration can be implemented in different types of sewage treatment plants with different aeration systems and process configurations. In general, on/off aeration has virtually no impact on the effluent concentration of the conventional parameters (BOD, TSS and TP) and results in a significant reduction in effluent total-N concentration. However, it should be noted that on/off aeration increases the sensitivity of nitrification due to the reduction in aerobic

retention time. This is because the slow growing nitrifying bacteria are active only under aerobic conditions. The total plant energy savings from the participating plants ranged from 6 - 45 % which corresponded to annual cost savings of \$3,500 - \$27,500. Comparing these savings to the retrofit costs show that the payback times for implementing on/off aeration ranged from a few months to about 1.5 year.

Table 3-1 Summary Results from the Four Participating Plants

Parameters	Units	Cobourg #2		Deseronto		Elmvale		Paris	
Type of Plant		CAS		EA/CS		EA		EA	
Design Capacity	MLD	11.7		1.4		1.5		7.1	
Current ADF	MLD	5.9		1.3		1.1		3.6	
Current Hydraulic Capacity	%	50		93		73		51	
HRT	h	12		12		22		42	
Type of Aeration		Mechanical Surface		Fine Bubble Membrane		Jet Aeration		Mechanical Surface	
Aeration Basin Influent									
CBOD	mg/L	107		95		65		139	
TSS	mg/L	142		128		85		207	
TP	mg/L	2.6		3.3		2.1		5.7	
$(NH_3 + NH_4^+)$-N	mg/L	11		18		11		N/A	
TKN	mg/L	24		23		14		42	
Final Effluent **On/Off Aeration →**		Before	With	Before	With	Before	With	Before	With
CBOD	mg/L	7	8	6	8	2	2	3	8
TSS	mg/L	5	5	9	11	4	4	5	11
TP	mg/L	0.4	0.4	0.4	0.3	0.1	0.1	0.6	0.3
$(NH_3 + NH_4^+)$-N	mg/L	3.7	1.4	1.2	6.2	0.1	0.2	1.8	4.7
TN	mg/L	23	17	8	9	14	8	N/A	11
On/Off Cycle Times	min/min	30/30 or 45/45		30/30 or 30/45		45/75 & 60/60		30/30	
Aeration On Time	%	50		44		44		75	
Specific Power Usage Before on/off aeration	KWh/m3	0.50		0.44		1.8		0.52	
Retrofit Cost	$	<1000		2700		8000		8200	
Annual Cost Savings *(based on total plant energy usage)*	$/yr	4000		3500		27500		5600	
Annual Percent Savings	%	6		**21**		**45**		**13**	

4 Screening Tools to Assess Plants for On/Off Aeration

The first step in considering on/off aeration for a wastewater treatment plant is to determine whether the plant is a suitable candidate. Both technical and economic factors must be considered in assessing the suitability of a plant for on/off aeration operation. These factors can be grouped under five headings:

- Aeration system
- Mixing capability
- Plant capacity and performance
- Influent loading and characteristics
- Cost/benefit analysis

4.1 Aeration System

4.1.1 Type of Aeration System

The type and flexibility of the aeration system are critical factors in assessing a plant for on/off aeration. Suitable aeration systems are those that can be cycled on/off without causing clogging problems during the off cycle. Examples include fine bubble membrane diffusers, coarse bubble diffusers, mechanical aerators and jet aerators (**Table 4-1**). Aeration systems that are not suitable for on/off aeration include rigid porous diffusers such as fine bubble stone, ceramic or plastic diffusers. These systems are susceptible to clogging with mixed liquor solids when the air is turned off during aeration cycling.

Table 4-1 Types of aeration system that are suitable and not suitable for on/off aeration

Suitable	Not Suitable
Fine bubble membrane diffusers	Fine bubble stone diffusers
Coarse bubble diffusers	Fine bubble ceramic diffusers
Mechanical aerators	Porous plastic diffusers
Jet aerators	

Another factor to consider is the type of blower used in diffused and jet aeration systems. Two types of blowers commonly used in aeration systems are positive displacement (PD) and centrifugal blowers. PD blowers are more common in small to medium sized plants while centrifugal blowers are used in larger plants. Generally, PD blowers are more easily controlled over a wide range of airflow rates than centrifugal blowers. The airflow rates from PD blowers can be controlled by controlling the blower speed using a variable frequency drive (VFD). Cycling PD blowers on and off is usually easier to implement than cycling centrifugal blowers. On/off cycling of centrifugal blowers is difficult due to the time required to reach maximum speed from start-up. Also, reducing the airflow rates from a centrifugal blower to low levels can lead to surging (i.e., the blower operates alternately at zero and full capacity), which can result in vibration and overheating.

4.1.2 Flexibility of Aeration System

Once it is determined that the type of aeration system is suitable for on/off operation, the flexibility of the system must be evaluated. This includes the ability to cycle on and /off without significantly impacting the aeration system itself or other processes or equipment that depend on the aeration system. The ability to cycle the aeration system will depend on the configuration of both the aeration system and the aeration control system.

4.1.3 Aeration System Configuration

Configurations of aeration systems vary widely from plant to plant. Mechanical aeration systems are generally simpler than diffused aeration systems. That is, mechanical aerators can be cycled without impacting other equipment or processes. For plants with multiple aeration tanks, each tank may be equipped with one or more mechanical aerators which may be cycled independently of the aerators in the other tanks. For diffused and jet aeration systems, the blower(s) may be supplying air to one or more aeration tanks, to other process units (e.g., aerobic digester or grit chamber), and to other process equipment (e.g., air lift pumps). This increases the interaction of the aeration systems with other processes and equipment, and thus increases the complexity of the aeration control system. Nevertheless, on/off aeration can be implemented successfully provided all the factors and the impacts of the interactions are considered. Examples of different scenarios and possible solutions using diffused aeration systems are given below:

1. One blower supplying air to the aeration tank(s) and no other process or equipment
   - *Cycle the aeration tank(s) by cycling the blower.*

2. One blower supplying air to the aeration tank(s) and other processes or equipment
   - *Cycle the aeration tank(s) by cycling the blower and evaluate the impact of the air OFF cycles on the other processes or equipment. In many cases this may not be a problem.*

For example, the air supply to aerobic digesters and grit chambers may be cycled without significantly impacting the plant's performance.

- *Cycle the air in the aeration tank(s) using air control valves and maintain constant airflow to the other processes or equipment by running the blower continuously. During the aeration OFF cycle, the blower can be operated at a lower speed using a variable frequency drive to provide the air required for the other processes and equipment.*
- *Cycle the air in the aeration tank(s) by cycling the main blower and use another (smaller or backup) blower to supply air to the other processes or equipment. In cases where the payback period is deemed to be attractive (e.g., less than 3 years), a small blower could be installed to operate the other processes or equipment.*

3. One blower supplying air to two or more aeration tanks operated in parallel

   - *Cycle all aeration tanks simultaneously by cycling the blower, or*
   - *Operate the blower continuously at a lower output capacity, and manipulate air control valves to switch the airflow from one tank to another.*

   The second approach would be preferred if plant is already equipped with air control valves, since there would be no need to cycle the blower on and off. If the plant is not equipped with air control valves and is equipped with centrifugal blowers, then it may be worthwhile to install air control valves to cycle the air since it is difficult to cycle centrifugal blowers on and off.

4. One blower supplying air to two or more aeration tanks operated in series

   - *Cycle all aeration tanks simultaneously by cycling the blower, or*
   - *Operate the blower continuously at a lower output capacity, and manipulate air control valves to switch the airflow from one tank to another, or*
   - *Cycle the aeration in the first pass only by using an air control valve and change the blower output capacity based on demand. For example, increase the blower capacity during the ON cycle and reduce it during the OFF cycle.*

   The first approach may be preferred if the plant is not already equipped with air control valves and it is too costly to install an air control system with air control valves. The second approach would be preferred if the plant is operating well below design capacity (i.e., less than 75%) and can alternately cycle multiple aeration tanks. The third approach would be preferred if the plant is operating near design capacity (i.e., greater than 75%). Cycling the first pass only provides effective denitrification without significantly affecting the nitrification capacity of the plant. Nitrate is returned to the first pass by the returned activated sludge flow and readily biodegradable BOD is provided by the influent wastewater.

4.1.4 Aeration Control System

The type and complexity of aeration control systems vary from plant to plant. Some plants are controlled manually while others are equipped with automatic control. Automatic control systems could range from a central computer control system, such as a supervisory control and data acquisition (SCADA) system, to a local control system, such as programmable logic controllers (PLCs) or timers. Plants with automatic control systems may implement on/off aeration by simply re-programming or modifying the control system to facilitate cycling of the aerators. Plants with manual control will require the installation of either timers (electronic or mechanical) or PLCs to facilitate cycling of the aerators.

4.1.5 Impact on Aerator Motor

Another important factor is the impact of on/off cycling (frequent restarts) on the aerator motor. If the type, flexibility and configuration of the aeration system are suitable for on/off aeration cycling, then the impact of frequent restarts on the aerator motors could be reduced or eliminated by installing either soft-start switches, variable frequency drives, or multiple coil motors.

4.2 Mixing Capability

The aeration system in STPs is used to provide both the oxygen and mixing requirements in the aeration tanks. Therefore, mixing during the aeration off cycle must be considered when assessing a plant for on/off aeration. The mixing requirements during the aeration off cycle will depend on the type of aeration system, rate of settling of the mixed liquor solids, length of the aeration off cycle, and configuration of the aeration tank.

4.2.1 Residual Mixing

Typically with mechanical and coarse bubble aeration systems, there is sufficient residual turbulence in the aeration tank to prevent the mixed liqour solids from settling out completely when the aerators are turned off. Influent and return activated sludge (RAS) flows also provide some degree of mixing during the aerator off cycle. Mixing due to residual turbulence and/or in-flows may be sufficient to keep the mixed liqour solids in suspension provided the aeration off time is not too long (i.e., greater than 45 min). Residual mixing is deemed to be sufficient if the solids and the liquid phase separation is higher than 80% of the tank's liquid depth at the end of the off-cycle.

4.2.2 Supplemental Mixing

Supplemental (or active) mixing may be provided in cases where the capability exists or where residual mixing is not sufficient. Approaches for implementing supplemental mixing during the aeration off cycle include:

1. *Low speed mixing* Mechanical aerators equipped with variable speed drive may be operated at a relatively low speed to provide gentle mixing without causing re-aeration of the mixed liquor.
2. *Pulse mixing* Diffused aeration systems equipped with air actuated valves may be capable of inducing pulse mixing by introducing a short burst of air at selected intervals during the air off cycle. The burst of air must be sufficient to provide re-suspension of the mixed liquor solids without introducing significant oxygen into the mixed liquor. This could be implemented where the blower is running constantly to supply air to other process units or aeration tanks, and aeration cycling is achieved by opening/closing air valves.
3. *Jet mixing* Jet aeration systems include blowers to provide air and jet pumps for recirculation of the mixed liquor. When the air is turned off, the jet pumps are normally capable of maintaining sufficient mixing in the aeration tank to keep the mixed liquor solids in suspension.
4. *Independent mixer* In cases where residual turbulence cannot provide sufficient mixing and existing equipment cannot provide supplemental mixing, an independent mixer may have to be installed to meet the mixing requirements during the aeration off cycle.

4.3 Plant Capacity and Performance

The current capacity and performance of a plant must be assessed relative to its design capacity and regulated effluent criteria when considering on/off aeration. Although a plant may not be required to nitrify (i.e., there is no effluent total ammonia or TKN limit), it is expected that the plant is nitrifying when considering on/off aeration. This is because the nitrate produced by nitrification during the air ON cycle is used in place of free oxygen for carbonaceous BOD removal during the air OFF cycle. Note on/off aeration <u>will</u> reduce the nitrifying capacity of a plant since nitrification only takes place during the air ON cycle (i.e., under aerobic condition). Carbonaceous BOD removal can occur during both the ON and OFF cycles.

In the following cases, careful considerations should be given when assessing a plant for on/off aeration:

1. The plant's current capacity is close to its design capacity (greater than 90%).
2. The plant has stringent effluent total ammonia or TKN limits (i.e., less than 2 mg/L).
3. The plant has a requirement for specific total-N reduction.

4.3.1 Nitrification Issues

Implementation of on/off aeration assumes that the plant is nitrifying or is capable of nitrifying. Although most plants in Ontario are currently not required to nitrify, many small to medium sized plants do achieve some degree nitrification. Some plants nitrify all year round while others only nitrify seasonally. While some plants achieve complete nitrification, others achieve only partial nitrification. Experiences have shown that nitrification performance can be improved by implementing consistent SRT control. A SRT control program must be implemented at the plant that is considering on/off aeration. This will improve the operator's understanding of the treatment process, and ensure more consistent operation and performance.

Note: As discussed in **Section 2**, the aeration requirement of a nitrifying plant is significantly greater than a non-nitrifying plant. Therefore if a plant is not nitrifying, the decision to operate the plant to achieve nitrification must consider the increase in aeration requirement.

4.3.2 Aeration Capacity

The aeration capacity of a plant must be capable of providing the oxygen required for both nitrification and BOD removal. Typical 24 hr DO profiles can be used to determine whether the plant has sufficient aeration capacity. If the DO profiles show adequate DO levels (greater than 2 ppm) during the highest loading periods of the day, then there should be sufficient oxygen at all other times of the day. Note, the oxygen transfer efficiency (or aeration capacity) of an aeration system is affected by a number of factors. For example, seasonally changes in wastewater and air temperatures, and changes in wastewater characteristics could have a significant impact on the aeration capacity of a plant. If the DO profiles show that the plant is operating at less than 2 ppm for certain time period in a day or in a year, it is possible to suspend on/off aeration temporarily during those times or reduce the air off cycle time.

During on/off cycling, the aeration system must be capable of quickly increasing the DO level in the aeration tank to 1-2 ppm when the aerator is turned ON (i.e., less than 25% of the ON cycle time). For example, if the ON cycle time is 30 min then the DO level should increase to between 1-2 ppm in less than 8 min or so. While some plant can achieve effective nitrification at a DO level of 1 ppm, the recommended minimum DO level for effective nitrification is 2 ppm.

4.4 Influent Loading & Characteristics

4.4.1 Industrial/Seasonal Load Changes

Extra consideration should be given to plants that received significant industrial inputs and those that are subjected to significant load changes. Industrial inputs could negatively impact on/off aeration and the plant's performance due to organic overloading or inhibition of nitrification. If the nature and frequency of industrial loadings are known, then the plant's operation could be adjusted accordingly. For example, on/off aeration could be suspended temporarily, or the air on time could be increased relative to the air off time when higher loadings are expected. The impact of seasonal load changes, such as spring runoff or seasonal industrial discharges, should also be considered. These load changes may also require temporary operational changes or suspension of on/off aeration if they cause problems at the plant.

4.4.2 Wastewater Characteristics

The important wastewater parameters for implementing on/off aeration are the alkalinity level and easily biodegradable BOD to TKN ratio. For wastewaters with low alkalinity levels, on/off aeration could be beneficial since denitrification recovers about half the alkalinity consumed during nitrification. Plants with specific total-N removal requirements (ie the sum of total ammonia and nitrate nitrogen in the effluent must not exceed a specified value) will need a sufficiently high BOD/TKN ratio (CBOD/TKN > 4) in the influent wastewater to provide the necessary BOD to reduce the nitrate-N during denitrification. The specific CBOD/TKN ratio required in the influent wastewater will depend on the total-N removal to be achieved. If the readily biodegradable BOD is not sufficient to reduce the TN level, then an external carbon source such as methanol may have to be added during the off cycle to reduce the nitrate to nitrogen gas. The work for the case studies described in this document did not include the use of external carbon sources.

4.5 Cost/Benefit Analysis

A cost/benefit analysis for implementing on/off aeration should be conducted at the screening stage. Although this analysis will compare the retrofit/implementation costs to the cost savings, it should also consider the benefit of improved effluent quality with on/off aeration. The factors to consider when estimating the retrofit/implementation costs and the cost savings expected from on/off aeration are discussed below.

4.5.1 Retrofit/Implementation Costs

The costs of implementing on/off aeration will include the costs of retrofitting the plant plus any additional costs during the testing and implementation phases. Retrofit costs include provisions for cycling the aerators, reducing impacts on the aerator motors, and provide mixing during the aeration off cycle (if needed). Testing and implementation costs may include additional sampling/monitoring and labour requirements during the early stages of implementing and evaluating on/off aeration. The factors with possible options to consider when estimating the cost of implementing on/off aeration are listed in **Table 4-2**. Obviously the estimated cost and time for implementing each option will vary from plant to plant, depending on the existing equipment at the plant, the configuration of the plant and the aeration system, and interactions with other processes and equipment.

Table 4-2 Factors, options and estimated cost/time to consider when estimating the cost of implementing on/off aeration.

Factors to Consider	Possible Options	Estimated Cost & Time Ranges
Cycling aeration system	Install electronic or mechanical timer	<$1000
	Modify computer control software or SCADA system	<$2000
	Re-program existing or install new PLC on aeration system	<$2000
	Install air control valves to switch air flow between tanks	Vary significantly
Reducing impact of motor restarts	Install soft-start switches	<$2000 / motor
	Install variable frequency drive (VFDs)	$5000 - $10000
	Other means (e.g. use double or multiple coil motor)	<$3000 motor
Mixing during aeration off cycle	Residual mixing	No cost
	Supplemental mixing	Vary significantly
Additional sampling/monitoring	Effluent and DO monitoring during implementation and evaluation stages	Vary significantly
Additional labour requirement	Implement process monitoring and SRT control. *(This should part of any plant's normal operating procedure).*	30-60 min per day

4.5.2 Cost Savings

The main cost saving from on/off aeration is due to aeration energy savings. For plants receiving low alkalinity wastewaters, additional cost savings may be realized from a reduction in chemicals needed to maintain adequate alkalinity in the wastewater.

Energy The extent of aeration energy savings will depend on the current energy efficiency of the plant relative to typical values for the same type and size of plant. The specific power usage (kWh/m3) is one parameter that can be used to compare a plant's energy efficiency. This is the plant's total annual energy consumption divided by the total annual wastewater flow. Evans and Laughton (1990) published average specific power usage for different types and sizes of plants in Ontario (see **Table 4-3**). These results can be used as a rough guide to assess the potential energy savings at a candidate plant. However, better estimates of energy cost savings can be determined using one of the approaches described in **Table 4-4**.

On/off aeration typically does not impact the demand power of a plant. Demand power is normally based on 15-minute average of power draw. When a motor is turned on, the duration of increased power draw is relatively short (less than a minute) and therefore does not impact the demand power. In some cases on/off aeration may result in the use of one blower instead of two, or the operation of one blower at a reduced capacity and switching airflow using air control valves. In these cases on/off aeration may result in a reduction of the demand power.

Alkalinity Plants receiving low alkalinity wastewaters (e.g., plants located in Northern Ontario) may require the addition of chemicals such as lime or caustic to maintain the pH level around the neutral range in the aeration tank. This is because nitrification consumes a significant amount of alkalinity in the wastewater (about 7.1 kg $CaCO_3$ per kg NH_4-N nitrified). During on/off aeration denitrification could recover up to 50% of the alkalinity consumed during nitrification. The chemical cost savings from on/off aeration can be estimated based on the wastewater characteristics, expected denitrification (nitrate reduction), and chemical costs.

Table 4-3 Average Total Energy Consumption by Ontario STPs (Evans and Laughton, 1990)

Facility Type	Specific Power Usage (kWh/m^3)		
	<10,000 m^3/d	10,000 – 40,000 m^3/d	>40,000 m^3/d
CAS	0.48	0.40	0.38
	<2,000 m^3/d	2,000 – 5,000 m^3/d	>5,000 m^3/d
EA	1.38	0.67	0.59

Aeration System Energy Consumption CAS = 55 % of total energy consumption
EA = 58 % of total energy consumption

Table 4-4 Two approaches for estimating aeration energy savings from on/off aeration.

Approach 1: Using Existing Power Bills and Typical Percentages

Annual Total Energy Cost (ATEC)	Using the plant's utility bills determine the annual energy consumption and annual total energy cost for entire plant (ATEC).
Aeration Energy Usage	Based on the results from the candidate plants in this study (more than four) the aeration system accounts for between 25-50 % of the plant's total energy usage and energy costs. Aeration energy cost = 25-50 % of ATEC
Aeration Energy Savings	Typical aeration energy savings = 20-50 % aeration energy cost
Energy Cost Savings ($/yr) =	**Aeration energy savings (%) x Aeration energy cost (% of ATEC) x ATEC ($/yr)** Assuming: Aeration energy savings = 20% Aeration energy = 50% of ATEC Energy cost savings = 0.2 x 0.5 x ATEC = 0.1 x ATEC

Note: Other major electrical users such as electrical heating during winter, other processes (SBR, aerobic digester) or sludge storage mixing could significantly affect the fraction of the annual total energy usage that is attributed to the aeration system.

Approach 2: Direct Measurement of Aeration Energy Consumption

Aeration System OFF time	Estimate the fraction of time that the aeration system will be OFF (Typically Aeration OFF time = 25 – 50 %)
Average Aeration Power Draw (**AAPD**)	Measure the average power draw of the aeration system (AAPA) over a typical 24 hr period. This could be done directly using: - a portable power analyzer, - a built-in power meter in the aeration control panel, or - current and voltage measurements, and calculated using an assumed power factor.
Daily Aeration Energy Usage (kWh/d)	Determine the daily aeration energy usage by: - direct measurement, or - calculated using AAPD (kW) x 24 hr/d
Daily Aeration Energy Savings (**DAES**)	Daily Aeration Energy Usage (kWh/d) x % Aeration OFF Time
Energy Cost Savings ($/yr) =	**DAES (kWh/d) x 365 d/yr x $0.07 /kWh**

Note: Adjustments to this approach may be required if the aeration system is not completely on and off during on/off aeration, or if supplemental mixing is required during the OFF cycle. The aeration system may not be completely on during the ON cycle if online DO control is used during the ON cycle and suspended during the OFF cycle. The aeration system may not be completely off during the OFF cycle if the aerator is used for slow mixing during the OFF cycle or if a blower is run at a reduced capacity during the OFF cycle to supply air to other process units or equipment.

5 Implementing On/Off Aeration

If the initial screening and assessment of a plant indicated that the plant is a suitable candidate for on/off aeration, the next steps in the process are:

1. Conducting on/off aeration trials
2. Implementing plant retrofits and operational changes
3. Evaluating and optimizing on/off aeration operation

5.1 Conducting On/Off Aeration Trials

Depending on the complexity of the treatment process and the aeration control system, on/off aeration trials could be conducted either manually or automatically. There are three essential components to consider when conducting on/off aeration trials:

1. Nitrification Issues
2. Aeration Cycling
3. Monitoring

5.1.1 Nitrification Issues

Before starting any on/off aeration trials, the first question to consider is: "Is the plant nitrifying?".

- If YES, then the on/off trials can go ahead provided that consistent nitrification can be maintained. This may be accomplished by implementing sludge retention time (SRT) control.

- If NO, then there are a number of options to consider:
  1. Is the plant required to nitrify?
     - If yes, then you should implement changes (e.g., SRT control) to ensure that the plant is nitrifying and then proceed with the on/off trials.
     - If no, then you should decide whether you would like the plant to nitrify.
  2. If you would like the plant to nitrify, implement operational changes (e.g., SRT control) to achieve consistent nitrification and proceed with the on/off trials.

3. If the plant is not nitrifying and you still want to go ahead with on/off aeration without nitrification, then the impacts on the plant's operation and performance are not fully known. Some possible impacts if this option is implemented are:

   → BOD breakthrough?

   → Settling problems?

   → Bio-P removal?

   → No negative impact?

The procedures and techniques described in this document assumed that <u>the plant is nitrifying when implementing on/off aeration</u>. The option of implementing on/off aeration without nitrification is not recommended because of the many unknowns and therefore is not discussed further in this document.

5.1.2 Aeration Cycling

On/off aeration trials are conducted by cycling the aeration system and monitoring the process parameters and effluent quality. Cycling the aeration system can be performed manually by switching the aerators on and off at specified time intervals, or automatically by setting the aeration control system to cycle the aerators. Some rules of thumb for setting aeration cycle times are as follows:

1. Total time for each cycle (ON time + OFF time) is not greater than 1/6 average HRT.
2. Start with equal on/off cycle times, or with the ON cycle greater than the OFF cycle.
3. Consider mixing capability during the OFF cycle when setting cycle times:
   - With no supplemental mixing → set maximum off time to 30-45 min
   - With supplemental mixing → maximum off time can be greater than 45 min
4. After several complete cycles, adjust the cycle times if necessary to get suitable DO profiles A suitable DO profile is when the DO level increase to above 1 mg/L within the first 25% of ON cycle and drop to around zero within the first 25% of the OFF cycle. For example, with a 30 min ON / 30 min OFF cycle, the DO level should increase to above 1 mg/L during the first 8 min of the ON cycle and drop to below 0.2 mg/L during the first 8 min of the OFF cycle.

Note: Care should be taken when shutting off or cycling the aerators (e.g., blowers). Consider the impact on the aerator motors and/or impact other treatment process units (e.g., aerobic digester, aerated grit chamber, SBR), equipment (e.g., air lift pumps), or other plant operation.

5.1.3 Monitoring

Monitoring is a key component of the on/off aeration trials. The key process parameters to monitor during on/off trials are DO levels in the aeration tank(s), solids settling during the off cycles, and aeration tank influent and final effluent concentrations.

DO profiles DO levels in the aeration tanks should be monitored over at least 3 on/off cycles and at different times of the day. Preferably, DO profiles should be obtained at suitable locations in aeration tanks over typical 24 hr periods. This information can be used to adjust the on/off cycle times to get more suitable DO profiles. D.O. should not exceed 4 mg/L during the on cycle since to save energy and minimize the time required to reduce D.O. to zero during the off cycle. D.O. should be able to increase to greater than 1 mg/L within 25% of the on cycle time and reduces to less than 0.2 mg/L within 25% of the off cycle time.

Solids Settling The rate and extent of solids settling in the aeration tank(s) should be monitored during the aeration off cycles. A quick and easy ways is visually checking the degree of solids settling at different locations in the aeration tank. A better means of assessing the degree of solids settling is to use a transparent sludge judge to measure the sludge blanket level at different locations in the aeration tank and at different times during the off cycle. Mixing is deemed to be sufficient if the solids and the liquid phase separation is higher than 80% of the tank's liquid depth at the end of the off-cycle.

Influent/Final Effluent The aeration tank influent and final effluent concentrations of total ammonia-N (or TKN), nitrate-N (or total-N), and of the conventional parameters (BOD, TSS and TP) should be monitored during on/off trials. Although on/off aeration typically does not have any negative impact on the conventional parameters, they should still be monitored. The main parameters are total ammonia-N and nitrate-N. All samples should be collected using 24 hr composite samples, starting after the plant had been cycling for at least a couple of HRTs. This will allow for new steady state concentrations of total ammonia-N and nitrate-N to be established in the aeration tank and for these changes to be noticeable in the final effluent. For plants with long HRTs (greater than 12 hr), mixed liquor samples may be taken directly from the aeration tank, filtered immediately, and then analyzed for total ammonia-N and nitrate-N. This will eliminate the retention time in the secondary clarifier and thus allow samples to be taken sooner after the start of on/off aeration cycling. The samples should be filtered to remove the biomass and thus eliminate biological activity in the samples after they have been taken and before being analyzed.

5.2 Implementing Plant Retrofits and Operational Changes

If the on/off aeration trials are successful and the results obtained are satisfactory, then the next step in the process is the implementation of the plant retrofits and operational changes to facilitate long term on/off aeration operation. The steps involved at this stage are described below:

1. Implement sludge mass control
2. Aeration cycling
3. Minimize impact of aeration cycling
4. Mixing during aeration off cycle
5. Other process / operational changes

5.2.1 Implement sludge mass control

Importance of Sludge Mass Control in the On/Off Aeration Process. The source of oxygen available during the off cycle of an on/off aeration process is the nitrate (NO_3^-) produced during nitrification. Therefore, nitrification is a critical aspect of the on/off aeration process. Two of the operational factors listed in the overview section as crucial for successful implementation of nitrification are:

- A nitrifying treatment plant must carefully monitor and control sludge inventory;
- A nitrifying treatment plant may require a longer SRT.

Sludge inventory control can be defined generally as the measurement of appropriate parameters to calculate the inventory or mass of suspended solids in the secondary treatment plant, and the regular wasting of the excess mass generated. The following paragraphs provide an overview of sludge inventory control rather than a step by step guide for implementation. For more details on sludge mass control implementation, there are numerous training manuals available.

Overview of Sludge Inventory Control There are several ways to control sludge mass in a treatment plant. Some examples include MLSS control, Food to Microorganism ratio (F/M) control and total sludge mass control. However, as discussed earlier, the SRT is directly related to the capability of the plant to nitrify. For this reason SRT control is the recommended approach for treatment plants that are required to nitrify. In addition, SRT control should be set up to include the mass of sludge in the clarifiers because of the impact of this mass on the total SRT required, on sludge settling characteristics and on the potential for denitrification and rising solids in the clarifiers. **Figure 5-1** illustrates the overall sludge mass inventory in a treatment

plant. For consistent control, it is best to measure the total sludge mass every day. A parameter that allows the operator to track the distribution of the mass between the aeration tanks and the secondary clarifiers is the sludge distribution ratio (SDR) which is also shown in **Figure 5-1**. The objective is to maximize the proportion of the total mass in the aeration tanks (i.e. maximize the SDR). This is usually achieved through appropriate adjustments to the return sludge flow rate. For most plants SDR should be maintained at 4 or higher.

After measuring the total sludge mass in the system, the mass to be wasted is estimated by dividing the total sludge inventory by a target SRT. For a nitrifying plant the target SRT will need to be greater than the minimum SRT for nitrification at the current mixed liquor temperature (see **Figure 2-3** for typical minimum SRTs). Although this minimum can be measured using specialized techniques, in many plants it will be based on experience. The actual SRT will depend on the total sludge mass wasted which will be comprised of both the mass wasted intentionally for SRT control and the mass of solids wasted unintentionally in the effluent (**Figure 5-2**).

Note that if the SRT required for nitrification is known, it will need to be adjusted for the aerobic fraction in an on/off aeration process. For example, if the total on/off cycle is 60 minutes with 40 minutes on and 20 minutes off, the aerobic fraction is:

Aerobic Fraction = 40/60 = 0.67

The new required SRT is:

New SRT = Old SRT/0.67.

5.2.2 Aeration Cycling

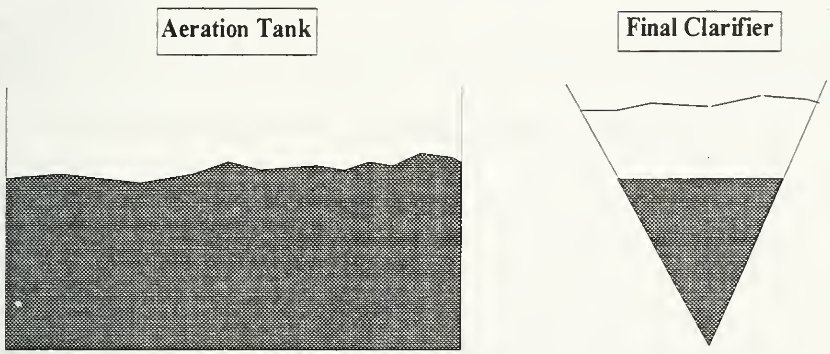
Retrofits to allow for cycling the aeration system is central to implementing on/off aeration. As discussed above (section ??), the nature and cost of the retrofits will depend on the type of aeration system, the plant and aeration system configurations, and the existing aeration control system. These systems should be inspected and evaluated to determine the best means of cycling the aerators to provide flexibility and to minimize the impact on other processes and equipment. Retrofit options to facilitate aeration cycling may include:

- installing electronic or mechanical timers on mechanical aerators or blowers,
- modifying computer control program in the plant's SCADA system,
- re-programming existing PLCs that control the aeration system, and
- installing and/or manipulating air control valves (e.g., actuator valve or butterfly valve) to switch air flows from one tank to another.

The aeration control system should provide the flexibility to allow the plant operator to change cycle times and to set different cycle times during different periods of the day. The aeration system should be capable of supplying the oxygen required for both nitrification and BOD removal over a shorter timeframe (i.e., fraction of ON time). The aerator capacity should not be increased to the extent that the DO levels overshoot (greater than 4 mg/L) during the ON cycle, since this will result in a waste of energy. It could also result in the DO level taking a long time to reduce to zero during the OFF cycle.

OVERVIEW OF SEWAGE TREATMENT PLANT

SLUDGE MASS INVENTORY



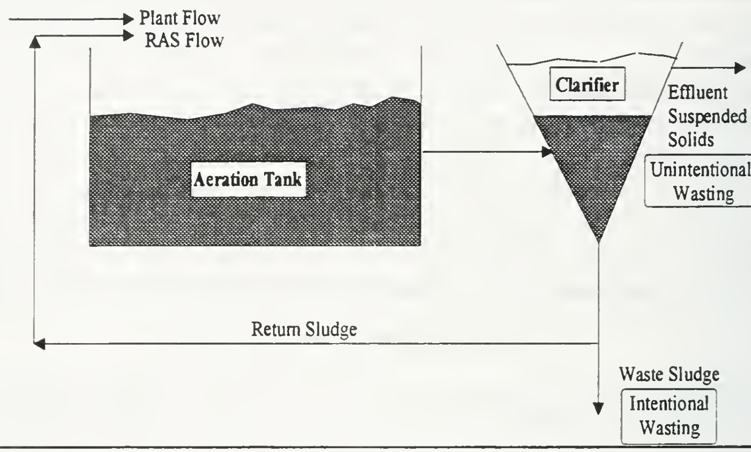
$$\text{Total Sludge Mass} = \text{Aeration Sludge Mass} + \text{Clarifier Sludge Mass}$$

$$\text{Sludge Distribution Ratio} = \frac{\text{Aeration Sludge Mass}}{\text{Clarifier Sludge Mass}}$$

Aeration Sludge Mass = mixed liquor solids concentration x aeration tank volume

Clarifier Sludge Mass = solids concentration in clarifier determined by a sludge judge x clarifier volume

Figure 5-1 Overview of STP sludge mass inventory.



a.) Sludge Wasting = Intentional Wasting + Unintentional Wasting

b.) Total Sludge Mass = Aeration Sludge Mass + Clarifier Sludge Mass

c.) $\text{Solids Residence Time (SRT)} = \dfrac{\text{Total Sludge Mass}}{(\text{Sludge Wasting})/\text{d}}$

d.) $\text{Waste Mass/day} = \dfrac{\text{Total Sludge Mass}}{\text{SRT(days)}}$

Figure 5-2 Important relationships in SRT control.

5.2.3 Minimize impact on aerator motors

The impact of on/off cycling on the aerator motors must be minimized. Options for reducing the impacts on aerator motors due to frequent re-starts include the use of:

- soft start switches on the motors,
- double or multiple coil motors,
- variable frequency drive (VFD) to control the motor speed during start-up and over a specified range.

These devices must be specified and installed by a licensed electrician or equipment supplier.

5.2.4 Minimize impact on other process units or equipment

Aeration cycling may impact other process units (e.g., aerated grit chamber, aerated channels and aerobic digesters) or air-operated equipment (e.g., airlift pumps) in the plant. In some cases the impacts on other process units or equipment may be negligible, while in other cases special provisions may be necessary to reduce the impacts. For example, air to the aeration tank and an aerobic digester may be cycled simultaneously without affecting either process. In other cases if the duration of the air off cycle is relatively short, the temporary interruptions of air to grit chambers or airlift pumps may not be significant. However, the impacts of aeration cycling on these process units and equipment should be assessed on a case by case basis.

Special provisions that could be used to eliminate the impact of aeration cycling on other process units or equipment include:

- operate a smaller separate blower or a back-up blower at a lower output capacity to provide the air requirements of the affected processes and/or equipment, or
- operate the main blower at a lower capacity during the off cycle to supply air to the affected processes and/or equipment, and turned off the air flow to the aeration tank using an air control valve.

5.2.5 Mixing during aeration off cycle

Mixing during the aeration off cycle is necessary to achieve efficient denitrification (i.e., proper contact between MLSS, BOD and nitrate), and to eliminate potential short-circuiting of influent wastewater. In some cases, residual (or passive) mixing in the aeration tank may provide satisfactory mixing, while in other cases supplemental (or active) mixing maybe necessary. Different types of residual and supplemental mixing are discussed in **Section 4.2**.

5.2.6 Other Process / Operational Changes

The implementation of on/off aeration may require other process or operational changes in order to perform effectively. While some changes may not be necessary for on/off aeration, they could be implemented to improve the overall operation and performance of the plant. Examples of other process and operational changes include:

- changing influent flow splits to multiple aeration tanks or trains,
- operate in step-feed mode,
- adjust RAS recycle rates and RAS flow splits to multiple aeration tanks,
- operating aeration tanks in series vs. in parallel, and
- connecting air headers from multiple blowers and use a common blower for more than one process.

The rationale and impacts of implementing these process/operational charges are described in **Section 5.3.2**.

5.3 Techniques for Evaluating / Optimizing On/Off Aeration

The techniques and parameters that are used to evaluate and optimize a plant's performance during on/off aeration operation are described in this section under the following headings:

- Evaluating on/off aeration operation
- Optimizing operating conditions
- Measuring plant's performance

Techniques used for evaluating a plant's performance during on/off aeration are DO and effluent monitoring. The main parameters used for optimizing a plant's performance are cycle times and target SRT, while the important parameters for measuring a plant's performance are effluent quality and operating costs.

5.3.1 Evaluating On/Off Aeration Operation

The main parameters that are directly influenced by on/off aeration are:

- DO levels in the aeration tanks,
- Effluent total ammonia and nitrate concentrations, and in some cases
- pH (or alkalinity) of the mixed liquor and mixed liquid settling (bulking) characteristics

These parameters provide feedback for optimizing the plant's performance, especially during the early stages of implementing on/off aeration or when there are significant changes at the plant. Examples include changes in wastewater characteristics, temperature, effluent discharge limits, and industrial loadings. Techniques for monitoring DO levels and effluent parameters are presented below along with discussions on how the information is used.

DO Monitoring Plants that are equipped with online DO monitoring will have continuous access to DO measurements and DO profiles that can be used to optimize the plant's operation. Plants that are not equipped with online DO monitoring will need to set-up a regular DO monitoring schedule. This could be performed using a portable DO meter connected to a chart recorder, or manually measuring the DO levels in the aeration tank at different times during the on/off aeration cycles and at different times of the day. However, it is recommended that a minimum of 2 sets of 24 hr DO profiles be collected on weekdays and weekends, and at different times of the year (seasonally). DO profiles should be collected during typical loading conditions.

The information from DO profiles and DO measurements can be used to adjust the cycle times, the aerator output capacity, or the flow split between aeration trains to improve the DO profiles. Suitable DO profiles consist of adequate DO levels during the ON cycle (DO > 1-2 mg/L) and near zero DO level during the OFF cycle (DO < 0.2 mg/L). The DO level should increase fairly quickly to over 1 mg/L during the first 25% of the aerator ON cycle and dropped to below 0.2 mg/L during the first 25% of the aerator OFF cycle. Too high DO levels (DO > 4 mg/L) during the ON cycle should be avoided since it results in a waste of energy and the DO level may not reach zero during the OFF cycle.

A DO level of at least 1-2 mg/L during the ON cycle (aerobic) is required for effective nitrification (ammonia removal) while a DO level of zero during the OFF cycle (anoxic) is required for effective denitrification (nitrogen removal).

Effluent Monitoring The main product from a wastewater treatment plant is the final effluent. Therefore monitoring the final effluent quality is essential for optimizing the plant's performance (i.e., the product's quality). It is recommended that 24 hr composite samples of the final effluent should be taken and analyzed for the following parameters:

- regulated or conventional parameters (typically cBOD, TSS and TP)
- total ammonia-N or TKN
- nitrate-N or total-N

At least once per week monitoring should be carried out over a minimum of 3 SRTs during summer and winter conditions, or when is any significant change at the plant (e.g., significant increase in loading conditions due to spring runoff or seasonal industrial inputs, start-up or shut-down of major process units, etc.).

Regulated Parameters Most municipal wastewater treatment plants in Ontario are currently regulated only for effluent cBOD, TSS and TP. An increasing number of plants are being regulated for effluent total ammonia-N, while only a few plants are regulated for effluent nitrate-N (or total-N). Although on/off aeration typically does not have a significant impact on the effluent cBOD, TSS and TP concentrations, these parameters should be monitored to ensure compliance. In some cases, on/off aeration may improve solids settling and thus lower the TSS and TP concentrations in the final effluent.

Effluent total Ammonia-N Effluent ammonia-N concentration from a treatment plant is monitored to determine the extent of nitrification. This is especially important for plants with effluent total ammonia limits (i.e., where ammonia toxicity in the receiving water is a concern). Since nitrification occurs only under aerobic condition, there will be no nitrification during the aeration OFF cycle once the DO level dropped to near zero. Thus, on/off aeration is recommended for plants with excess nitrification capacity. The effluent total ammonia concentration is used to determine the extent of nitrification and to optimize the process parameters (i.e., ON/OFF cycles and SRT) to ensure adequate nitrification.

Plants with effluent total ammonia limits should be operated and optimized to achieve the effluent ammonia concentrations specified in the Certificate of Approval (C of A). Plants with no effluent total ammonia limits are typically operated to achieve effluent ammonia concentrations of less than 5 mg/L. This will result in near complete nitrification and more consistent performance. Partial nitrification is not recommended since a plant could loss nitrification with minor plant upset. Experience showed that it is difficult to regain nitrification especially during cold weather conditions.

Effluent Nitrate Effluent nitrate-N concentration is monitored to determine the extent of denitrification and total nitrogen (TN) removal. Since sewage treatment plants in Ontario typically do not have TN limits the main motivation for TN removal is the energy savings resulting from denitrification during on/off aeration. Thus the effluent ammonia and nitrate concentrations could be used to optimize the process parameters (e.g., on/off cycle times, recycle rates, and aeration capacity) to achieve the desired balance between effluent total ammonia and nitrate-N concentrations and energy savings.

For a typical municipal sewage treatment plant, a self-imposed target effluent nitrate concentration during on/off aeration is typically 10 mg/L or less. The main factors affecting denitrification (nitrate reduction) are the availability of nitrate and easily biodegradable BOD, and the length of time when the DO level is at or near zero (during the off cycle).

Alkalinity Plants receiving weakly buffered (or low alkalinity) wastewater could experience a significant drop in pH in the aeration tank as a result of the alkalinity consumed during nitrification. This may require the addition of lime or caustic to keep the pH around the near neutral range. During on/off aeration, there is a partial recovery of alkalinity due to denitrification and therefore the addition of lime or caustic could be eliminated/reduced. The alkalinity of the mixed liquor or final effluent should be monitored in plants receiving weakly buffered wastewater. This information could be used to optimize the addition of lime or caustic to maintain an adequate pH level.

Note most sewage treatment plants in southern Ontario have sufficient alkalinity in the wastewater and therefore do not require pH adjustments.

5.3.2 Optimizing On/Off Aeration

Optimizing on/off aeration is an ongoing process. It starts during the initial on/off aeration trials and continues after implementing on/off aeration and SRT control. Evaluating and optimizing the process parameters normally take place simultaneously. Monitoring of the process parameters provides the data that are evaluated and used to optimize the plant's performance. Key process parameters used for optimizing a plant's performance during on/off aeration are:

- Cycle Times
- Target SRT
- Other parameters (e.g., DO set-point, blower capacity, mixing, flow split, and recycle rate).

As in all cases, the most important consideration during optimization is defining the objective(s) of the optimization. Different treatment plants may have different objectives for implementing and optimizing on/off aeration. Some examples are:

- maximize energy savings
- maximize total nitrogen removal
- maximize energy savings while keeping effluent total ammonia below a specified limit
- improve settling
- reduce foaming.

Although the primary objective for implementing on/off aeration in many plants is to maximize energy savings, there maybe certain limitations or secondary objectives such as maximizing total-N removal or achieving tight effluent total ammonia limits. Since the reason for implementing on/off aeration and the operational flexibility vary from plant to plant, the following sections discuss the general impacts of the key process parameters on a plant's performance.

Adjusting Cycle Times Optimizing the on/off cycle times will be required in nearly all cases of implementing on/off aeration. This will start during the initial on/off trials and continue during the implementation and evaluation phases. Setting the on and off times will depend on a number of factors, including HRT, SRT, wastewater flow and load variations, and extent of mixing during the off cycle. In general, the impacts of changing on/off cycle times are:

- Increasing the percent ON time will increase nitrification and lower the effluent ammonia-N concentration,
- Increasing the percent OFF time will increase denitrification and lower the effluent nitrate-N concentration, and
- Increasing the ON+OFF time per cycle will reduce the frequency of motor restarts.

On/off cycle times are adjusted to achieve or maintain a desired level of performance. Reasons for changing cycle times include:

- different loading conditions during the day vs. night, or weekdays vs weekends;
- seasonal variations in wastewater flows, temperature, or loading conditions;
- seasonal effluent total ammonia limits (e.g., different summer and winter ammonia limits); and
- seasonal or periodic industrial discharges;

When setting and optimizing on/off cycle times, there are a number of factors that should be considered. Some of these factors are discussed in previous sections and are listed below:

- Ensure the OFF cycle is less than 45 minutes when supplemental mixing is not available;
- Ensure the ON cycle is not longer than one hour to elevate DO level too high (> 4 mg/L);
- Avoid too long total cycle time relative to average HRT in the aeration basin (<1/6 HRT);
- Consider setting different cycle times at different times of the day and of the week;
- Consider suspending on/off aeration or reducing the off cycle time during high loading conditions.

Adjusting SRT SRT control is normally implemented to achieve and maintain consistent operation, especially with respect to nitrification performance. The minimum SRT required to achieve nitrification is affected by:

- mixed liquor temperature (seasonal),
- wastewater characteristics (e.g., industrial inputs), and
- on/off cycle times.

This means that the target SRT may have to be adjusted when there are significant changes in any of the above conditions. The target SRT should be adjusted before or immediately after a significant change in the above conditions is known. For example the SRT should be increased during early winter because of the expected drop in wastewater temperature during the winter. Typical SRTs for complete nitrification would be between 4 and 8 days in the summer and 12 and greater than 15 days in the winter in Ontario.

Effluent total ammonia is the key parameter to determine if the target SRT is appropriate. Too short an SRT will lead to high effluent total ammonia concentration and loss of nitrification. On the other hand, too high an SRT could lead to a high MLSS concentration. This could result in low DO conditions, foaming, bulking, and increased solids loading to the final clarifier. Adjusting the target SRT will be based on the plant's performance data and the operator's experience and knowledge of the plant.

Adjusting Other Process Parameters In addition to target SRT and cycle times, there are other parameters that could be adjusted to optimize the plant's performance during on/off aeration. Some of these parameters include:

- DO set-point
- Aeration capacity
- Flow splits
- Mixing
- RAS Recycle

Although frequent adjustments of these parameters may not be necessary, periodic checks should be conducted and the appropriate adjustments made to optimize the plant's performance. Reasons for changing the above parameters are discussed in the following paragraphs.

DO Set-Point For treatment plants equipped with on-line DO monitoring and control, on/off aeration may be implemented with the DO control system running during the ON cycle and suspended during the OFF cycle. The aerators are controlled to maintain a specific DO set-point during the ON cycle. This minimizes over aeration and too high DO levels during low loading periods. Although the DO set-point could be adjusted to improve energy savings, it should be maintained in the range of 1-3 mg/L to achieve effective nitrification during the aerobic phase.

Aeration Capacity Adjusting aeration capacity is typically required at plants with excess aeration capacity. For treatment plants that are not equipped with on-line DO control, the aeration capacity during the ON cycle may be adjusted by other means to avoid excessively high or low DO levels. For example, blowers and mechanical aerators equipped with variable frequency drive (VFD) may be manually controlled to limit their maximum output during the ON cycle. A maximum output limit could also be applied to blowers and mechanical aerators controlled by an on-line DO control system. At the start of an ON cycle the difference between the measured DO and the DO set-point will be large and therefore the on-line control system may call for maximum output from the blower or aerator. If the maximum output is not restricted the DO level could overshoot the DO set-point. This results in a waste of energy and may also destabilize the controller. Other means of limiting blower capacity is to reduce the number of blowers in operation or change the pulley to reduce the maximum output capacity.

Flow Splits For plants with more than one aeration tanks or trains the influent flow could be split between the aeration tanks or trains to optimize the plant's performance. This is especially applicable at plants with multiple aeration tanks that are not identical. The influent flow could be distributed to the aeration tanks to better match the aeration capacity or retention time of each tank. Influent flows could also be split to operate in step-feed mode at plants with a single plug flow aeration tank, or with multiple aeration tanks operated in series. The extent of flow splits will depend on an assessment of the process design, aeration cycling in each tank and feedback information from process parameters, such as DO profiles and effluent quality.

Mixing Mixing during the aeration OFF cycle is required to keep the mixed liquor solids in suspension and to mix the influent and RAS flows in the tank without re-aerating the mixed liquor. The objective is to improve the contacts between the MLSS (biomass), influent flow (BOD) and RAS recycle (nitrate) to improve denitrification and to reduce potential short-circuiting. If mixing is achieved by residual turbulence during the off cycle then there is no flexibility to improve mixing. However, active (or supplement) mixing may be manipulated to improve the level of mixing. Active mixing during the OFF cycle may be achieved by intermittent short burst of air (pulse mixing), jet pump mixing from jet aerators, mechanical aerator operated at low speed using a VFD, or a separate mixer.

RAS Recycle The flow rate and distribution of the RAS recycle to the aeration tanks could also be manipulated to improve performance. In addition to returning biomass to the aeration tank, the RAS recycle also return the nitrate required for denitrification. The sludge distribution ratio (SDR), which is the sludge mass in the aeration tank to the sludge mass in the final clarifier, can be used to adjust the recycle rate to increase the SDR. Higher recycle rates also increase the return of nitrate to the head of the aeration tank to be reduced by easily biodegradable BOD during the air OFF cycle. However, too high recycle rates could lead to higher solids loading rates to the final clarifier, increased pumping costs and reduced solids concentration in clarifier underflow. All of these factors must be considered when adjusting the RAS recycle rate. Under normal circumstances, SDR should be kept greater than 4.

5.3.3 On/Off Aeration Simulation Case #2: Optimization of On/Off Aeration

This section presents a simulated example to illustrate the impact of adjusting various process parameters on the performance of an on/off aeration process. An understanding of these interactions is important for optimizing the process. The same example plant used in the earlier simulation case is used here. Key design and operating conditions for the example plant are repeated in **Table 5-1** and the same activated sludge layout in BioWin is repeated in **Figure 5-3.**

The objective of this case study is to illustrate the impact of adjusting:

- aeration cycle times; and
- SRT.

How does adjusting aeration cycle times impact on/off aeration performance? Two simulated optimization examples are used to illustrate this impact. In both cases, the aeration cycle of 1 hour on / 1 hour off is used as a basis of comparison (i.e. this is the same simulation used for Simulation Case #1 earlier in this document). The results from the 1 hour on / 1 hour off simulation example showed that at the peak loading time of the day, the DO concentration did not reach an adequate level during the air on portion of the cycle to ensure complete nitrification.

Example #1 As a result, an alternative cycle time of 1.5 hours on / 0.5 hours off was investigated. The simulation with this cycle (Error! Reference source not found.) showed that complete nitrification could be achieved while still maintaining excellent total-N removal (i.e. nitrate concentrations were less than 5 mg/L throughout the day). The disadvantage of this cycle time is that the energy savings would be reduced. However, this approach could be further enhanced to provide a compromise. For example, a 1 hour on / 1 hour off cycle could be used through most of the day, while a 1.5 hour on / 0.5 hour off cycle could be used at the peak loading times.

Example #2 In this optimization example a 0.75 hour on / 1.25 hour off cycle was simulated. The results from this simulation (Error! Reference source not found.) illustrate the danger of setting an air on time that is too short. In this case, the short air on time significantly reduces the nitrification performance of the plant.

Example #3 *Providing a longer SRT does not always improve nitrification performance in an on/off aeration process.* This example provides some additional insight into the interactions present in the on/off process. One possible approach for improving the nitrification performance of the 0.75 hour on / 1.25 hour off cycle operation would be to increase the SRT with an initial expectation that this would provide more nitrifiers and thus more nitrification. However, the simulation results for a 20 day SRT (Error! Reference source not found.) indicate that there is no improvement in nitrification performance because the dissolved oxygen levels during the air on time are lower for a 20 day SRT than for a 12.5 day SRT. The reason is that with a longer SRT, the sludge yield is lower, and therefore less carbon and nitrogen is removed with the waste sludge, resulting in a higher overall oxygen demand. In other words, increasing the SRT will not improve the nitrification performance if SRT is not the factor limiting the performance.

Table 5-1 Design and operating parameters for on/off aeration simulation

Influent Flow	
Average Daily Flow (ADF)	10,000 m^3/d
Bioreactor	
Volume = 5,000 m^3	Hydraulic Retention Time (HRT) = 12 hours at ADF
Final Clarifier	
Area = 500 m^2	Surface overflow rate (SOR) = 20 $m^3/m^2/d$ at ADF
Sludge Wastage Rate	200 m^3/d
Solids Retention Time (SRT)	12.5 days
Air Supply Rate	2.5 m^3/s

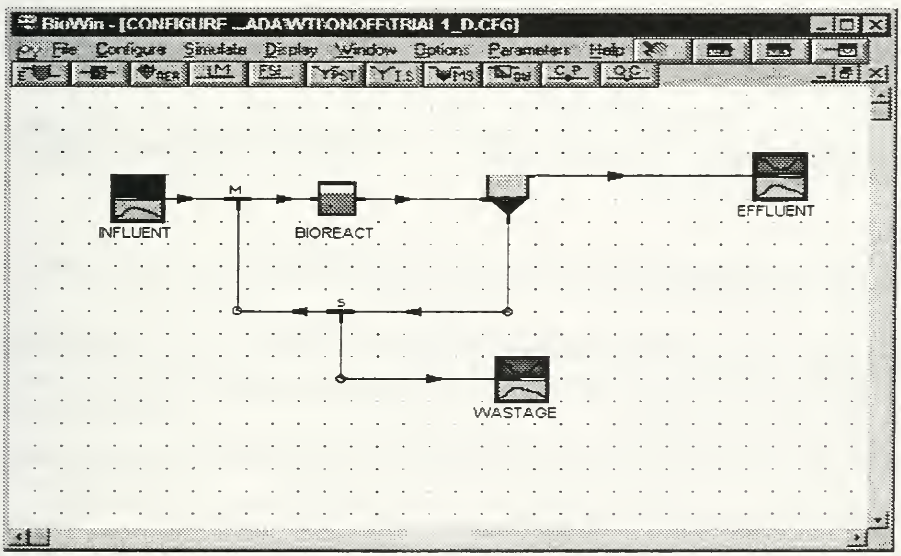


Figure 5-3 Simple activated sludge layout used in the BioWin process simulator.

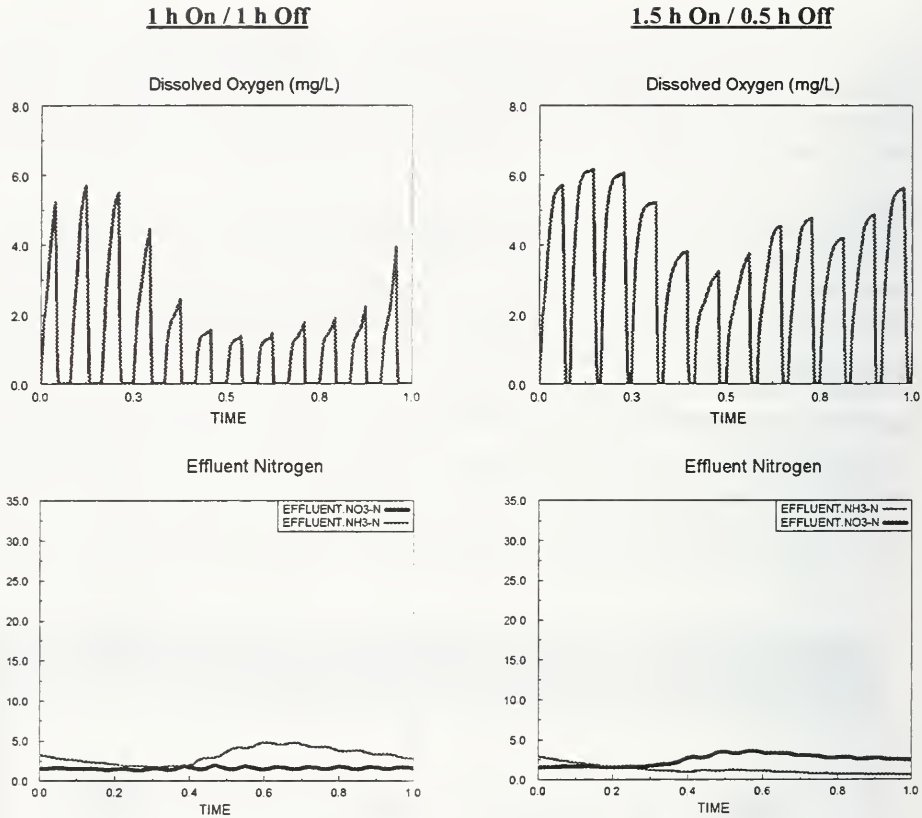


Figure 5-4 Results of simulations for optimization example #1 (*time in units of day*).

<u>Example #1</u> Impacts of increasing On cycle time from 1 h on/1 h off to 1.5 h on/0.5 h off:

1. *Significantly higher average DO level and thus higher energy consumption (average DO increased from 2-3 mg/L to 4-5 mg/L);*
2. *Slightly lower effluent (NH_3 + NH_4^+)-N (average NH_3-N dropped from 3-4 mg/L to below 2 mg/L);*
3. *Slightly higher effluent NO_3-N (average NO_3-N increase from about 2 mg/L to about 3 mg/L).*

In this case the benefit of slightly lower effluent *(NH_3 + NH_4^+)-N* must be weighed against the significantly higher energy consumption. If the plant has a tight *(NH_3 + NH_4^+)-N* limit, then a longer on time could be used and the aeration output capacity could be reduced to lower the average DO level.

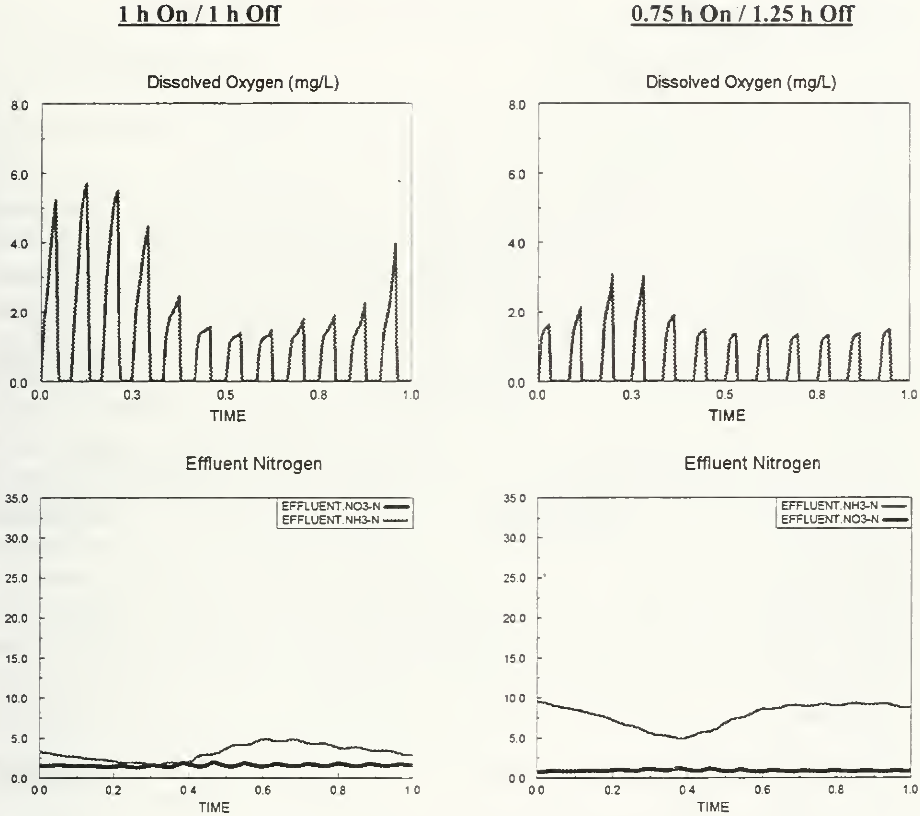


Figure 5-5: Results of simulations for optimization example #2 (*time in units of day*).

<u>Example #2</u> Impacts of increasing Off cycle times from 1 h on/1 h off to 0.75 h on/1.25 h off:

1. *Lower average DO level (average DO decreased from 2-3 mg/L to below 2 mg/L), and thus lower energy consumption;*
2. *Significantly higher effluent* $(NH_3 + NH_4^+)$*-N (average in* $(NH_3 + NH_4^+)$*-N increased from 3-4 mg/L to above 7 mg/L);*
3. *Slightly lower effluent* NO_3*-N (average* NO_3*-N decreased from about 2 mg/L to about 1 mg/L).*

In this case the benefit of lower energy consumption (higher energy savings) must be weighed against the higher effluent $(NH_3 + NH_4^+)$*-N* and also the increased sensitivity of the plant to load variations. This may be appropriate for plants with no $(NH_3 + NH_4^+)$*-N* limit.

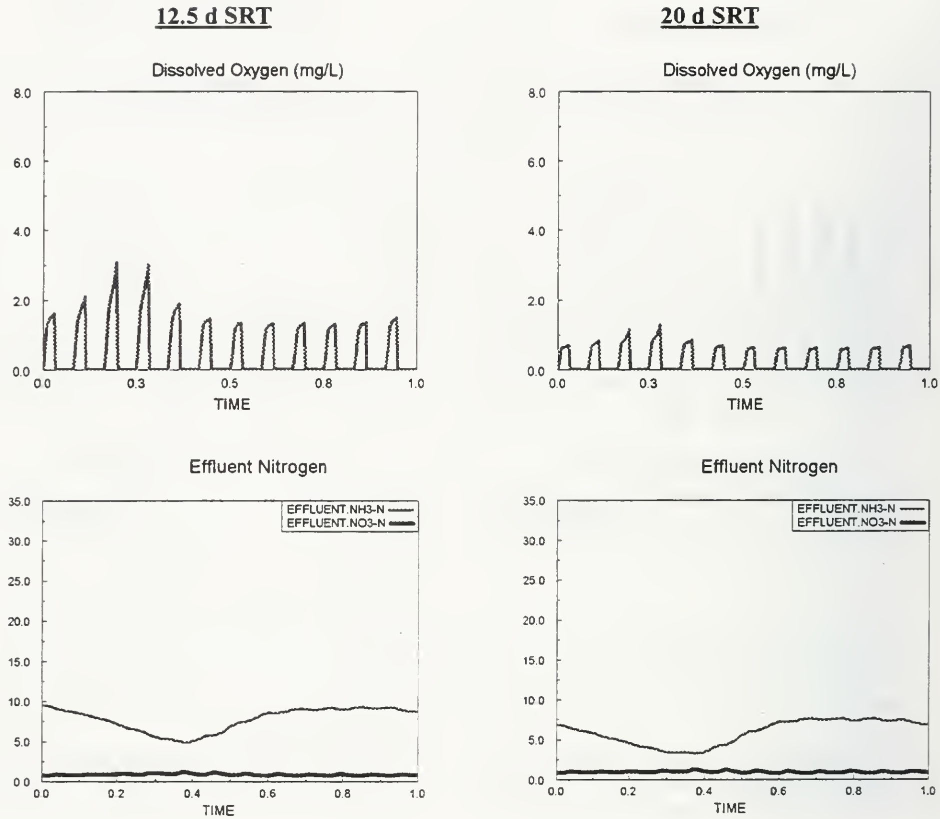


Figure 5-6 Results of simulations for optimization example #3 (*time in units of day*).

Example #3 Impacts of increasing SRT and maintaining the cycle times at 0.75 h on/1.25 h off:

1. *Lower average DO level (average DO decreased from just below 2 mg/L to less than 1 mg/L);*
2. *Slightly lower effluent ($NH_3 + NH_4^+$)-N (average ($NH_3 + NH_4^+$)-N dropped from 7 to about 6 mg/L);*
3. *Almost no change in effluent NO_3-N (average NO_3-N remained at about 1 mg/L).*

In this case the results showed that increasing the SRT may not necessarily lower the effluent (NH3 + NH4+)-N. Adequate DO seems to be the limiting condition. Higher SRT results in higher MLSS which could lead to low or limiting DO conditions. Such conditions could cause the growth of filamentous organisms and lead to foaming or bulking problems. The SRT should therefore be lower to reduce the MLSS and the percent ON time (or aeration capacity) should be

increased to increase to the DO level, especially if a low effluent $(NH_3 + NH_4^+)$-N concentration is required.

5.3.4 Measuring Performance

The key parameters used for measuring the performance of a STP during on/off aeration are the effluent quality and the operating cost. The importance placed on effluent quality versus operating cost will vary from plant to plant as it will depend on effluent discharge limits and the reason for implementing on/off aeration. On/off aeration could be implemented to achieve higher total-N reduction, energy savings, reduce foaming and bulking, or improve settling.

Effluent Quality The important parameters for measuring effluent quality are the regulated parameters specified in the plant's certificate of approval (C of A). For most sewage treatment plants in Ontario, the regulated effluent parameters are BOD, TSS and TP. However, an increasing number of plants are also being regulated for effluent total ammonia-N. Only a few plants are regulated for total-N. The effluent limit and sampling frequency for each parameter are specified in the plant's C of A. Plants that do not have effluent total ammonia and total nitrogen limits will normally sample for these parameters at the same time when sampling for the regulated parameters. Typical self-imposed targets for effluent total ammonia-N and total-N during on/off aeration are 5 and 10 mg/L or less, respectively. All effluent samples should be collected using 24 hr composite samples under typical flow and loading conditions.

Cost Savings

Energy One of the main reasons for implementing on/off aeration is to realize aeration energy savings. This is because aeration energy cost is a significant fraction of a plant's total operating cost. Therefore aeration cost savings due to on/off aeration is another parameter used for measuring performance. One approach for estimating energy cost savings during on/off aeration is to compare the plant's current utility bills with those from the same months from previous years. When comparing utility bills, note whether there have been other changes at the plants that may account for some of the difference in energy utilization. One common consideration is electrical heating during the winter months. Difference in energy consumption may be due to difference in ambient temperature from one winter to the next.

Another approach for estimating energy savings due to on/off aeration is to record daily energy consumption and run on/off aeration for a specified period (1-2 weeks) and continuous aeration for the same length of time under similar operating conditions. Daily energy consumption could be measured using the plant's main power meter or by connect a power analyzer to the aeration

system *(Note: This must be performed by a licensed electrician)*. The difference in average daily energy consumption will provide an estimate of the daily energy savings due to on/off aeration. This can then be converted to cost savings by using the rate structure from the utility bill or by contacting the local utility office. The daily cost savings can then be used to estimate monthly or annual cost savings by multiplying by the appropriate number.

Alkalinity In some STPs, additional cost savings may be realized during on/off aeration as a result of a reduction in chemicals required for pH adjustment. This will be more typical in Northern Ontario or other areas where the buffering capacity (or alkalinity) of the influent wastewater is low. The reduction in chemical cost as a result of on/off aeration can be estimated using a similar approach as described for estimating energy savings.

Appendix A

Case Studies:

On/Off Aeration at Participating Plants

Plant Description

Cobourg #2 WPCP is a conventional activated sludge plant (ASP) with a design flow of 11.7 MLD. The plant consists of two parallel trains with two circular primary clarifiers, two square aeration tanks and two rectangular secondary clarifiers (one clarifier was in use during the study). Mixed liquors from the aeration basins were combined before entering the secondary clarifier. The return activated sludge (RAS) flow was split equally into the aeration tanks. The final effluent is chlorinated in a chlorine contact chamber before discharging directly into Lake Ontario. The plant is also equipped with a sequencing batch reactor (SBR) for treating leachate from a nearby municipal landfill.

Aeration System Each aeration tank is equipped with one mechanical surface aerator. Tank #1 has a two-speed 20/30 Hp draft tube aerator and tank #2 has a 60 Hp variable speed aerator with an impeller near the bottom of the tank. The plant is equipped with an on-line DO monitoring and control system. This is used to control the aeration capacity by controlling the speed of the aerators and the liquid level in the aeration tanks.

Operation Prior to On/Off Aeration The average daily flow (ADF) was 5.9 MLD, or about 50% of design flow. This corresponded to a hydraulic retention time (HRT) of 12 h. The plant received primarily residential wastewater, plus a small volume (about 0.23 MLD or less than 5% of ADF) of pretreated landfill leachate. Historical operating data showed that the plant was achieving at least partial nitrification year round and the regulated effluent parameters (BOD, TSS, TP) were well below their discharge limits. The average power consumption of the entire plant was 3050 kWh/d and the specific power usage was 0.5 kWh/m3 of wastewater flow.

Implementing On/Off Aeration

Screening Initial screening to evaluate the suitability of the plant for on/off aeration was carried out by conducting a site visit and a review of the plant's design and operating data. The results of this screening are summarized below:

1. Plant/Capacity — Conventional ASP operating at about 50% of design capacity
2. Aeration — Mechanical surface aerators
Train 1 - Two speed aerator (20/30 HP)
Train 2 - Variable speed aerator (60 HP)
Online DO monitoring and control system
3. Mixing — Tank 1 – Residual turbulence due to mechanical aerator

	Tank 2 – Low speed mixing due to variable speed mechanical aerator
4. Wastewater	Mainly municipal wastewater with a small amount (about 5%) of pretreated landfill leachate
5. Nitrification	Achieving at least partial nitrification year round
6. Effluent limits	No effluent ammonia-N or total-N limit
7. Energy	Specific power usage of 0.5 kWh/m3 is typical for the size and type of plant. This also included the energy consumed by the on-site SBR.
8. Retrofit Cost	Cost for modifying on-line DO control system software
9. Savings	Aeration energy saving was estimated to be about 20% since the aerators were already tightly controlled by the online DO control system. This corresponds to less than 10% savings based on total energy usage if the aeration system accounts for less than half the total energy usage.

Retrofit/Operational Changes Retrofit and operational changes made as part of implementing on/off aeration are as follows:

1. SRT Control
   - A sludge mass control program was implemented about two months prior to starting on/off aeration in order to achieve consistent SRT control and nitrification performance.
2. Cycling Aerators
   - The online DO control system software was modified to allow cycling of the aerators based on fixed on and off cycle times.
   - Cycle times were set by the operator to achieve alternate cycling of the two aerators (one aerator on while the other was off).
   - Operator has the flexibility to change cycle times, to run (or suspend) on/off aeration, and to run (or suspend) on-line DO control.
   - When running, the online DO control system was on during the ON cycle and suspended during the OFF cycle.
3. Mixing
   - In Tank 1 the two-speed aerator was turned off during the OFF cycle and mixing was provided by residual turbulence in the tank.
   - In Tank 2 the variable speed aerator was operated at a low speed

during the OFF cycle to provide the necessary mixing.

4. Other Changes
   - *Changed Influent Flow Split to Trains 1 & 2 from 50/50 → 35/65* Initially, the influent flow was split equally between the two aeration tanks. Since the aeration capacity of aerator 1 (20/30 Hp two speed aerator) was lower than aerator 2 (60 Hp variable speed aerator), the flow split was changed from 50/50 to 35/65 (35% going to tank 1 and 65% going to tank 2), to better utilized the capacity of the aerators.

Optimization The following changes were made to optimize the plant's performance during on/off aeration.

1. Cycle Times
   - Initially, the on and off times for each aerator were set at 30 min on/30 min off and the on-line DO control system was turned off.
   - After a few months the on-line DO control system was then turned on during each aerator's ON cycle to control the aerator's output based on fixed DO setpoints.
   - After several months, the cycle times were increased from 30/30 min to 45/45 min for each aerator. This reduced the re-start frequency of the aerator motors without changing the overall fraction of on and off times (equal on and off times)
2. Target SRT
   - The target SRT was adjusted based on seasonal variations in wastewater temperature, effluent ammonia concentrations, and the operator's experience.
   - The operator maintained the MLSS within certain desirable upper and lower limits based on his experience at the plant.
3. Other Parameters
   - RAS flow split to the aeration tanks was adjusted periodically to control the solids being returned to the two tanks.

Results and Discussion

The SRT control program was set-up in July 1997 and on/off aeration was implemented in September 1997. The plant's operation and performance were closely monitored and evaluated over a year (October 1997 – September 1998) as part of this study. The data from this period were compared to the corresponding data from the previous year (October 1996 - September 1997) when the plant was operating in continuous aeration mode. The average operating and performance data for the periods before and with on/off aeration are summarized in **Tables A1-1** and **A1-2**, and the highlights of the results are listed below:

- The ADF and HRT for the periods before and with on/off aeration are comparable.
- During on/off aeration the aerators were operated with either 30/30 or 45/45 on/off cycles (in minutes) so that each aerator was off about 50% of the time.
- There was no impact on the regulated effluent parameters (cBOD, TSS, TP) during on/off aeration operation.
- Both the efficiency and consistency of nitrification improved significantly following the implementation of the SRT control program (see **Figure A1-1).** The average NH3-N decreased from about 3.7 mg/L to less than 1.5 mg/L. More significantly, monthly average NH_3-N concentrations fluctuated widely between < 1mg/L and 11 mg/L before SRT control; after SRT control was initiated, monthly NH_3-N concentrations dropped from about 11 mg/L to 1 mg/L within 2 months and remained less than 2 mg/L for the next 11 months including the winter period.
- Effluent TKN decreased only slightly during on/off operation due to the reduction in NH3-N. The results suggest that there is a significant fraction of slowly or non-biodegradable organic-N in the wastewater.
- Effluent TN remained fairly high during on/off aeration with only a modest reduction of about 25 %. This is due to the high effluent TKN and also the relatively high effluent NO3-N level (approx. 9 mg/L). The high NO3-N may be due to the low recycle rate at the plant (about 40%) where sufficient NO3-N is not returned to the aeration tanks for complete denitrification.
- During continuous aeration mode, the aeration system accounts for about 25% of the plant's total energy consumption.
- During on/off aeration mode, the aeration energy saving was about 24%. This corresponded to about 6 % savings based on the plant's total energy costs.
- The retrofit cost for implementing on/off aeration was less than \$1000 and the annual energy cost savings was about \$4000 (to modify the online DO control software). Thus the payback time was about 3 months. The energy cost and cost savings are plotted in **Figure A1-2**.

Table A1-1 Average operating parameters before and with on/off aeration

Operating Parameters	ADF	HRT	On/Off CycleTime	Aeration ON	Energy Usage	Energy Cost
	MLD	H	Min/min	%	MWh/yr	$/yr
Before On/Off	6.05	12	-	100	1113	77,097
With On/Off	5.52	13	30/30 or 45/45	50	1050	73,173
Annual Savings					**6 %**	**$4000**

Table A1-2 Average effluent parameters data before and with on/off aeration

Parameters	CBOD	TSS	TP	NH3-N	TKN	TN
			mg/L			
Primary Effluent	107	142	2.6	11	24	-
Final Effluent						
Before On/Off	7	5	0.4	3.7	10	23
With On/Off	8	5	0.4	1.4	8	17

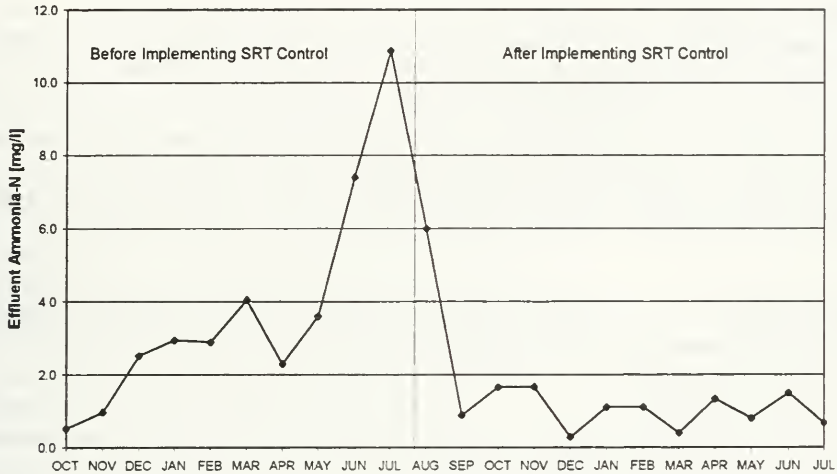


Figure A1-1 Impact of consistent SRT control on nitrification efficiency.

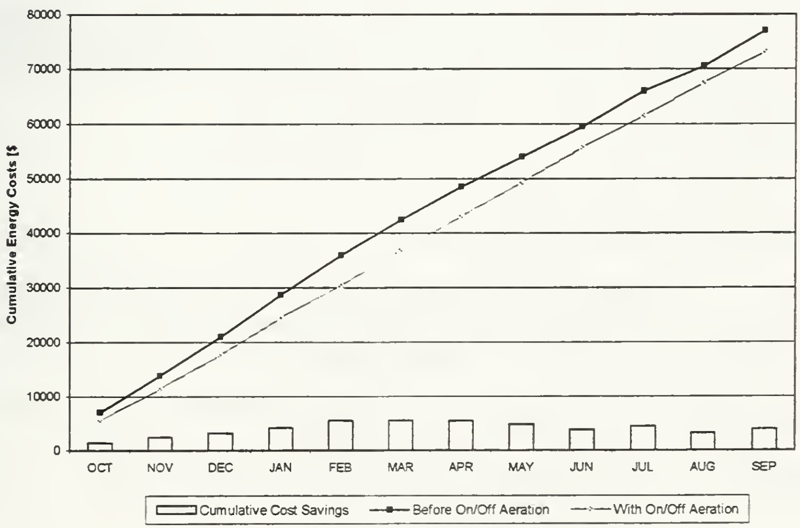


Figure A1-2 Cumulative energy cost and cost savings at the Cobourg #2 WPCP

Plant Description

Deseronto WPCP is an extended aeration (EA) activated sludge plant (ASP) with a design flow of 1.4 MLD. It is a circular package plant with the aeration basin and aerobic digester forming the outer annulus and the final clarifier in the centre. The plant could be operated in either extended aeration or contact stabilization mode. It is typically operated in EA mode where the raw wastewater and RAS recycle enter the aeration basin at the head of the tank. The final effluent is chlorinated in a chlorine contact chamber before discharging directly into the Bay of Quinte in Lake Ontario.

Aeration System The aeration system consists of fine bubble membrane diffusers with full floor coverage and three 20 HP Brook Hansen positive displacement blowers. Two of the blowers are equipped with programmable variable frequency drives (VFD). Only one blower is required to provide the air needed for the aeration basin, aerobic digester and an airlift pump for the RAS recycle. The plant is equipped with on-line DO monitoring, but does not have automatic DO control capability. The VFDs on the blowers can be adjusted manually by the operator based on the DO levels in the aeration tank at different times of the day.

Operation Prior to On/Off Aeration The plant was operating in EA mode with an ADF of 1.3 MLD, or about 93% of design flow. This corresponded to an HRT of 12 h. The plant receives primarily residential wastewater. Although the plant is not required to nitrify, it achieved almost complete nitrification year round. The regulated effluent parameters (BOD, TSS, TP) were well below their discharge limits. The average power consumption for the entire plant was 570 kWh/d and the specific power usage was 0.45 kWh/m3 of wastewater flow. This power usage is relatively low for the size and type of plant.

Implementing On/Off Aeration

Screening Initial screening to evaluate the suitability of the plant for on/off aeration was carried out by conducting a site visit and a review of the plant's design and operating data. The results of this initial screening are summarized below:

1. Plant/Capacity — Extended aeration ASP operating at about 93% of design capacity
2. Aeration — Fine bubble membrane diffusers with full floor coverage
   Three 20 HP positive displacement blowers, two equipped with programmable VFDs
   Online DO monitoring (no automatic control)

3. Mixing	On/off trials during site visit showed that residual turbulence and in-flow mixing was sufficient to keep the mixed liquor solids in suspensions for over 30 min when the air was turned off.
4. Wastewater	Mainly municipal wastewater
5. Nitrification	Achieving almost complete nitrification year round
6. Effluent limits	No effluent ammonia-N or total-N limit
7. Energy	Specific power usage of 0.45 kWh/m3 is very low for the size and type of plant. This is due to fine pore aeration and tight manual control of the blowers.
8. Retrofit Cost	Cost for purchasing and installing timers on the blowers
9. Savings	Aeration energy saving was estimated to be about 40% based on shutting off the air for about 50% of the time. This corresponds to about 20% savings based on total energy usage if the aeration system accounts for about half the total energy usage.

Retrofit/Operational Changes The retrofit and operational changes made as part of implementing on/off aeration are as follows:

1. SRT Control
   - A sludge mass control program was implemented in September 1997, about two months prior to starting on/off aeration. The necessary process control tests were performed 2-3 times per week.
2. Cycling Aerators
   - A programmable electronic timer was installed in October 1997 to facilitate on/off operation of the two blowers with VFD.
   - The operator has the flexibility to change the cycle times and suspend on/off aeration at anytime.
   - On/off operation was started in Nov. 1997 with 30/30 minutes cycles.
3. Mixing
   - No retrofit was made for mixing. Mixing was provided by the in flows and residual turbulence in the tank after the air is turned off.
4. Other Changes
   - *No other changes were made at the plant* - The air to the aerobic digester and the RAS airlift pump was supplied by the same blower

supplying air to the aeration basin. Thus the air flow to aerobic digester and airlift pump was also cycled on/off.

Optimization The following changes were made to optimize the plant's performance during on/off aeration.

1. Cycle Times
   - On/off cycle times were initially set at 30min on/30min off. One blower was operated for about 12 hr per day (or 50% of the time).
   - Shortly after start-up the off cycle time was increased during the night (low loading period). One blower was then operated for about 10.6 hr per day (or 44% of the time).

2. Target SRT
   - The target SRT was adjusted based on seasonal variations in wastewater temperature, effluent ammonia levels, and the operator's experience.
   - In January and in April 1998, the plant experienced some temporary sludge storage problems which limited the operator's ability to waste the required quantities of sludge to maintain the target SRT.
   - In February 1998, the operations staff lowered the target SRT from 20 to 15 days to relieve some of the difficulties in controlling the sludge mass, particularly since the RAS flow from the clarifier is pumped using an airlift and it does not operate during the air OFF cycle.

3. Other Parameters
   - *Adjust blower capacity during the ON cycle* - The blower capacity was adjusted manually using the VFD to compensate for the load variations to the plant during the day.
   - *Operate in contact stabilization mode* - The plant was operated in contact stabilization mode for about one week during mid-January 1998 due to extreme high flow conditions.

Results and Discussion

The SRT control program was implemented in September 1997, the plant was retrofitted in October 1997, and on/off aeration was initiated in November 1997. The plant's operation and performance were closely monitored and evaluated over a 12 months period (October 1997 – September 1998) as part of this study. The monitoring data from this period are compared to the corresponding data from the previous 12 months period (October 1996 - September 1997), when the plant was operating in continuous aeration mode. The average operating and performance data for the periods before and with on/off aeration are summarized in **Tables A2-1** and **A2-2**. The highlights and discussion of the results are presented below:

- The plant was operated in on/off aeration mode for 8 months (November 1997 – June 1998). During the fourth week of June 1998, the plant was switched to continuous aeration to re-established nitrification which had been lost during the winter and spring. Nitrification was restored by the end of June 1998, but the staff continued to operate the plant in continuous aeration mode until mid-September (about 2.5 months) when it was switched back to on/off aeration mode.

- The plant began losing nitrification in February 1998 and lost nitrification completely by May 1998 (see **Figure A2-1**). A review of the process control worksheets indicated that the plant had been operating at an SRT between 20-40 days prior to losing nitrification. In February 1998 the plant staff lowered the SRT to less than 20 days and maintained it at this level until May 1998 when it was returned to between 20-30 days. Complete nitrification was re-established by the end of June 1998 about one week after the plant was switched to continuous aeration mode.

- The plant was operating in on/off aeration mode while it was not nitrifying in the winter and spring. No negative effects were observed in the regulated effluent parameters (cBOD, TSS and TP). As expected, the effluent ammonia-N and TKN concentrations increased during this period as shown in **Figure A2-1**.

- The ADF, and hence the HRT, during the periods before and with on/off aeration are comparable (Table D1).

- At any time, only one 20 HP blower was operated to supply air to the aeration basin, aerobic digester and RAS airlift pump. The air to these processes and equipment was cycled during on/off cycling of the blower. No negative impact on the aerobic digester or airlift pump was observed.

- During on/off aeration the blower was operated for about 10.6 hr per day (or 44 % of the time). Cycle times were set at 30min on/30min off, or 30min on/45min off during low loading periods.

- The plant continued to produce a good quality effluent after implementing on/off aeration. The operating staff have not experienced any equipment operational problems resulting from on/off operation, and have observed improved sludge settling characteristics.
- The average effluent concentrations for the regulated parameters (cBOD, TSS, TP) before and after implementing on/off aeration were practically unchanged.
- As explained above, the plant lost nitrification during the winter and had difficulty re-establishing nitrification due to the low mixed liquor temperature and reduced aerobic retention time during on/off aeration. This demonstrates the increased sensitivity of nitrification during on/off aeration, particularly during cold weather conditions.
- The average effluent total-N before and during on/off aeration was unchanged. The relatively low effluent total-N concentration prior to on/off aeration suggests that the plant was achieving partial denitrification. Denitrification was improved following the implementation of on/off operation but the average total-N remained unchanged due to the increased effluent NH_3-N resulting from the lost of nitrification during the winter.
- Two weeks of intense energy monitoring was performed during the summer 1998. The results showed that the blower accounted for about 66% of the plant's total energy usage during continuous aeration and about 40% during on/off aeration. Aeration energy saving due to on/off aeration was about 160 kWh/d, or about 38% of the plant's total energy usage.
- Comparing the plant's total energy usage for the 8 months period with on/off aeration (Nov 97 – Jun 98) with the corresponding 8 months period from the previous year (Nov 96 – Jun 97) showed that the average total energy savings due to on/off aeration was about 21%. This corresponds to an annual energy cost savings of approximately $3500.
- The cost for implementing on/off aeration (installing electronic timers and repairing the DO monitoring system) was about $2700. Thus the payback time was less than one year. The energy cost and cost savings are plotted in **Figure A2-2**.

Table A2-1 Average operating parameters before and with on/off aeration

Operating Parameters	ADF	HRT	On/Off CycleTime	Aeration ON	Energy Usage	Energy Cost
	MLD	H	Min/min	%	MWh/yr	$/yr
Before On/Off	1.3	12	-		208	16,650
With On/Off	1.2	13	30/30 or 30/45	44	164[b]	13,154[b]
Annual Savings					**21 %[a]**	**$3500[b]**

(a) Percent energy and cost savings were calculated by comparing the energy usage and cost for the periods Nov 96 – Jun 97 (continuous aeration) and Nov 97 – Jun 98 (on/off aeration).

(b) The annual energy usage, energy cost and cost savings with on/off aeration were estimated using the percent savings with on/off aeration (21%) and the annual energy usage (208 MWh/yr) and energy cost ($16,650/yr) with continuous aeration (Oct 96 – Sep 97).

Table A2-2 Average effluent parameters data before and with on/off aeration

Parameters	CBOD	TSS	TP	NH3-N	TKN	TN
			mg/L			
Primary Effluent[a]	95	128	3.3	18	23	-
Final Effluent						
Before On/Off[b]	6	9	0.4	1.2	3	8
With On/Off[c]	8	11	0.3	6.2	6	9

(a) Average primary effluent concentrations (Oct 96 – Sept 98)

(b) Average final effluent concentrations with continuous aeration (Oct 96 – Sept 97)

(c) Average final effluent concentrations with on/off aeration (Nov 97 – Jun 98)

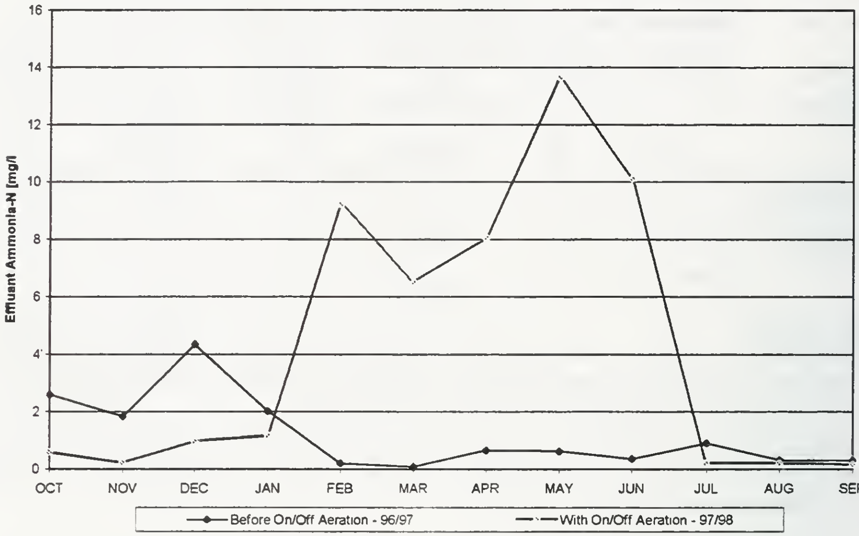


Figure A2-1 Effluent ammonia-N concentration before and with on/off aeration

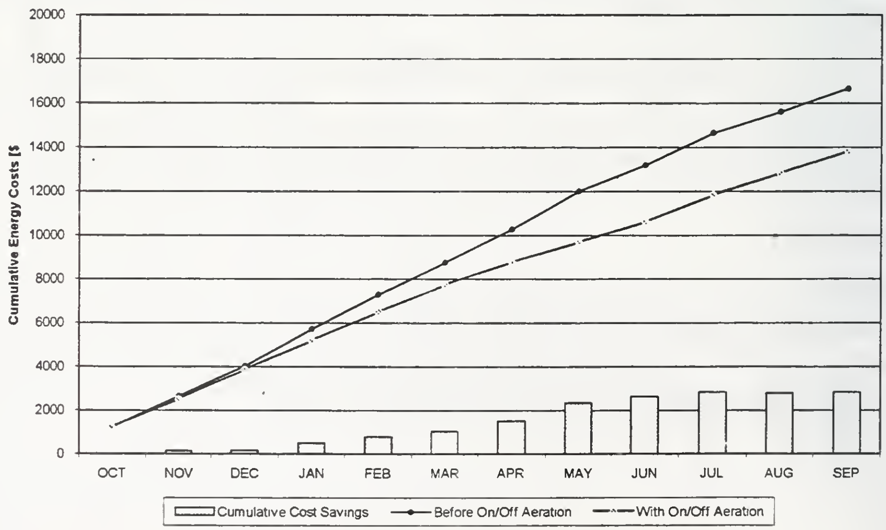


Figure A2-2 Cumulative energy cost and cost savings at Deseronto WPCP.

Plant Description

Elmvale WPCP is an extended aeration (EA) activated sludge plant (ASP) with a rated design capacity of 1.5 MLD. The plant has two trains, each consisting of a rectangular aeration tank with a small baffled section and a circular final clarifier. The baffled section in the aeration tank was designed to operate as an anoxic zone if required. Raw wastewater enters the aeration basin in the baffled section, while the RAS recycle flow enters the aeration basin both before and after the baffle. Final effluent is filtered using dynamic sand filters and disinfected using ultraviolet light. The plant discharges into the Wye River which flows into Severn Sound. The plant is equipped with aerobic digesters and six months sludge storage capacity on-site.

Aeration System The aeration system consists of jet aerators and positive displacement blowers. There are two 50 HP blowers (100% backup) for the aeration tanks and two 40 HP blowers (100% backup) for the aerobic digester. The blowers can be operated at 50, 75 or 100% capacity by changing the size of the pulleys. In each aeration tank, the jet aeration system consists of a 5 HP mixing pump is the small baffled section and a 10 HP mixing pump in the larger section. The plant does not have any online DO monitoring or control capability.

Operation Prior to On/Off Aeration The plant has been operating with continuous aeration throughout the aeration tank (including the baffled section). The ADF was approximately 1.2 MLD, or about 80% of the current rated design flow. This corresponded to an average HRT of 42 h in the aeration tanks. Since the plant receives primarily residential wastewater and it is not required to nitrify, it appears that the plant is significantly underrated (or over designed). The plant achieved complete nitrification year round and the regulated effluent parameters (BOD, TSS, TP) were well below their discharge limits. The average power consumption for the entire plant was 2151 kWh/d and the specific power usage was 1.79 kWh/m3 of wastewater flow. This power usage is fairly high for the size and type of plant.

As a result of the high energy cost and apparent excess treatment capacity at the plant, a number of plant retrofits and operational changes were implemented to reduce energy cost while maintaining the excellent effluent quality at the plant. The changes made prior to on/off operation are:

- *January 1997* A common air header was installed to connect the blowers for the aerobic digester with the blowers for the aeration tanks.
- *June 1997* One 50 HP blower was re-wound with a double coil to improve its energy efficiency. This also eliminated the need for a soft start switch to be installed for cycling the blower during on/off aeration.

- *July 1997* One aeration tank was put out of service which reduced the average HRT to about 21 h based on one tank.

Implementing On/Off Aeration

Screening A site visit was conducted during the spring of 1997 and the plant's design and operating data were reviewed. Elmvale WPCP was selected for implementing on/off aeration for the following reasons:

1.	Plant/Capacity	Extended aeration ASP operating with excess treatment capacity
2.	Aeration	Jet aeration which provides both aeration and mixing One 50 HP positive displacement blowers with a double coil and turn down capability. Three additional PD blowers (two 40 HP, one 50 HP) Manual DO monitoring using a YSI DO meter/probe
3.	Mixing	Mixing during the air off cycle provided by jet aerator pumps
4.	Wastewater	Mainly municipal wastewater
5.	Nitrification	Achieving complete nitrification year round
6.	Effluent limits	No effluent ammonia limit
7.	Energy	Specific power usage of 1.79 kWh/m3 is fairly high for the size and type of plant. This is the average usage prior to the changes identified above.
8.	Retrofit Cost	Cost for installing timer on the 50 HP re-wound blower
9.	Savings	Aeration energy saving was estimated to be about 50% based on shutting off the air for about 50% of the time. This should correspond to about 30% total energy savings assuming the aeration system accounts for about 60% of the total energy usage.

Retrofit/Operational Changes The retrofit and operational changes made as part of implementing on/off aeration are as follows:

1. SRT Control
   - A sludge mass control program was implemented in September 1997, about one month after the plant initiated on/off aeration. Typically,

SRT control is implemented prior to starting on/off operation.

2. Cycling Aerators
- The plant's electrician installed a mechanical timer on the 50 HP re-wound blower in July 1997 to allow on/off operation.
- The operator has the flexibility to change the cycle times and suspend on/off aeration at anytime. The timer setting could be changed using 15 min intervals.
- On/off cycling was initiated in August '97 with 30min on /30min off.

3. Mixing
- No retrofit was made for mixing. The jet aerator pumps ran continuously and provide sufficient mixing during the air off cycle.

4. Other Changes
- *No other changes were made at the plant* - Air to the aerobic digester and aeration basin was supplied by the same blower, thus the aerobic digester aeration was also cycled on/off.

Optimization The following changes were made to optimize the plant's performance during on/off aeration.

1. Cycle Times
- *July 1997* - On/off cycle times were initially set at 30min on/30min off. One 50 HP blower was operated 12 h per day at 100 % capacity.
- *August 1997* - The cycle times were changed to 60min on/60min off after 24 h DO monitoring showed that the DO levels remained above 3 mg/L during both the on and off cycle throughout the day.
- *October 1997* - The blower capacity was reduced from 100% to 50% after 24 h DO monitoring showed that the DO levels were too high (>5 mg/L) during the on cycle.
- *December 1997* - The cycle times were again adjusted to 45min on/75min off during AM hours (low loading period) and 60min on/60min off during PM hours (high loading period). The blower was operated for about 10.5 h per day (or 44% of the time).

2. Target SRT
- The target SRT was adjusted based on seasonal variations in wastewater temperature and the operator's experience.

3. Other Parameters
- *Reduced blower capacity* - In October 1997, the blower capacity was turned down from 100% to 50% by changing the pulleys.

Results and Discussion

The plant operators participated in training workshops in July 1997 on implementing SRT control and on/off aeration. The timer for cycling the blower was installed in July 1997, on/off aeration was started in August 1997, and SRT control was implemented in September 1997. The plant's operation and performance were closely monitored and evaluated for about a year (August 1997 – July 1998) as part of this study. The monitoring data from this period were compared to the corresponding data from the previous year (August 1996 – July 1997) when the plant was operating in continuous aeration mode. The average operating and performance data for the periods before and with on/off aeration are summarized in **Tables A3-1** and **A3-2**, and the highlights of the results are presented below:

- The ADF was slightly lower during the period with on/off aeration as compared to the previous year (**Table A3-1**). The average HRT prior to on/off aeration was about 42 h because both aeration tanks were in operation. One aeration tank was taken out of service just before on/off aeration was implemented and thus the HRT was reduced to about 27 h.
- After installing the common air header in January 1997, one 50 HP blower was used to supply air to both the aeration basins and the aerobic digester. During on/off aeration, the air to both processes was cycled when the blower was cycled. No negative impact on the aerobic digester was observed.
- After optimizing the on/off cycles, the blower was operated for about 10.5 hr per day (or 44 % of the time). Cycle times were set at 45min on/75min off during AM hours (low loading period) and 60min on/60min off during PM hours (normal loading period).
- The plant continued to produce excellent effluent quality during on/off aeration. The operating staff have not experienced any equipment operational problems resulting from on/off operation.
- Average concentrations of the regulated effluent parameters (cBOD, TSS, TP) were virtually the same before and during on/off operation.
- The plant continued to achieve complete nitrification during on/off operation. The average effluent NH3-N concentration was less than 0.5 mg/L.
- Average effluent TN reduced by about 40% as a result of denitrification during on/off aeration. The effluent TN concentration decreased from 14 mg/L with continuous aeration to about 8 mg/L with on/off aeration (see **Figure A3-2**).
- As discussed above, a number of plant retrofits and operational changes were made prior to and as part of implementing on/off aeration. The impacts of these changes on power demand and energy consumption (or savings) are summarized in **Table A3-3**. The results showed that the estimated total energy saving from these changes agrees fairly well with the actual

energy savings, while the actual decrease in power demand is greater than the estimated decrease in power demand. The reason for the difference in power demand is not known.

- Operational changes implemented during on/off aeration accounted for about half of the total energy savings. Cycling of the blower accounted for about 19 % of the total energy savings.
- The annual energy cost saving from all the changes was about 45% or $27,500 per year. The energy cost and cost savings are plotted in **Figure A3-3**.
- The cost for installing the common air header and rewinding the blower was about $7500 and the annual cost saving from these changes (plus shutting down one aeration basin) was about $13,500.
- The cost of implementing the changes for on/off aeration (installing a timers) was about $500. The annual cost saving resulting from the changes made during the on/off aeration study was about $14,000.
- Note this is not a typical case. Extensive effluent and DO monitoring and evaluation were performed during the implementation and optimization stages of on/off aeration. The costs of these activities are not included above.

Table A3-1 Average operating parameters before and with on/off aeration

Operating Parameters	ADF	HRT	On/Off CycleTime	Aeration ON	Energy Usage	Energy Cost
	MLD	h	min/min	%	MWh/yr	$/yr
Before On/Off	1.2	42[(a)]	-		785	62,652
With On/Off[(b)]	1.0	27	45/75 AM 60/60 PM	44	434	35,134
Annual Savings					**45 %**	**$27,500**

(a) Two aeration tanks were in operation just before on/off aeration study began. Only one aeration tank was in operation during the study.

(b) Plant was operation in continuous aeration mode for about 1 month during June/July 1998. This was <u>not</u> corrected for when calculating the annual energy and cost savings.

Table A3-2 Average effluent parameters data before and with on/off aeration

Parameters	CBOD	TSS	TP	NH3-N	TKN	TN
			mg/L			
Primary Effluent[(a)]	65	85	2.1	11	14	-
Final Effluent						
Before On/Off[(b)]	2	4	0.1	0.1	1	14
With On/Off[(c)]	2	4	0.1	0.2	1	8

(a) Average primary effluent concentrations (Aug 96 – Jul 98)

(b) Average final effluent concentrations with continuous aeration (Aug 96 – Jul 97)

(c) Average final effluent concentrations with on/off aeration (Aug 97 – Jul 98). Includes 1 month with continuous aeration.

Table A3-3 Impacts of Retrofits/Operational Changes on Energy

Retrofit/Operational Changes	Changed in Power Demand [kW]	Energy Savings [kWh/d]	Fraction of Total Savings [%]
Prior to On/Off Study			
Shut down one aeration train Turned off jet aerator pumps (10 HP + 5 HP)	11.2 → 0	269	26
Re-wound one 50 HP blower Improved blower efficiency	37.5 → 28.1	225	22
During On/Off Study			
Turned down blower from 100 to 50% Reduced blower output & power draw	28.1 → 14.0	337	33
Blower OFF 56% of the time Blower off about 13.5 h per day	14.0 off 13.5 h/d	189	19
Estimated Total Reductions	35	1020	100
Actual Total Reductions	**60**	**1014**	

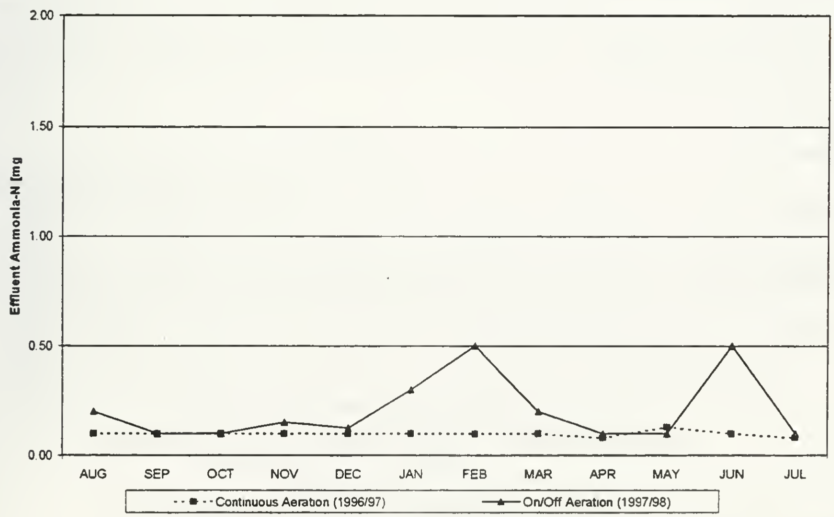


Figure A3-1 Effluent ammonia-N concentration before and with on/off aeration

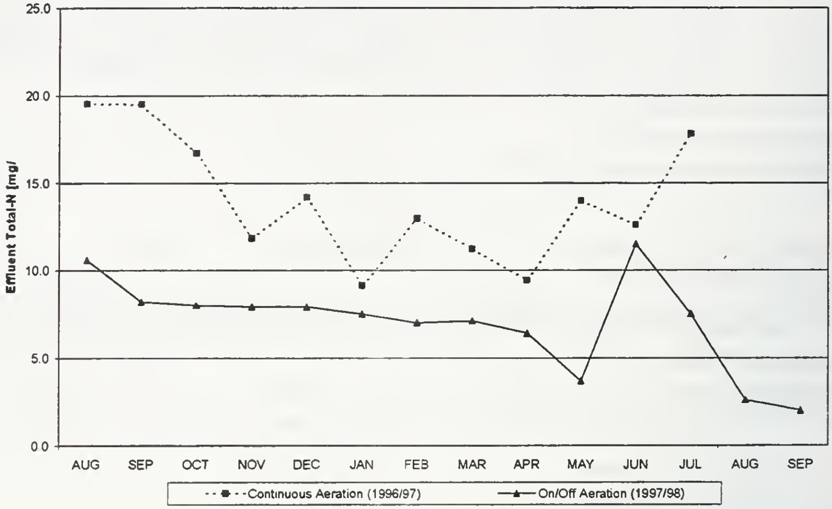


Figure A3-2 Effluent total-N concentration before and with on/off aeration

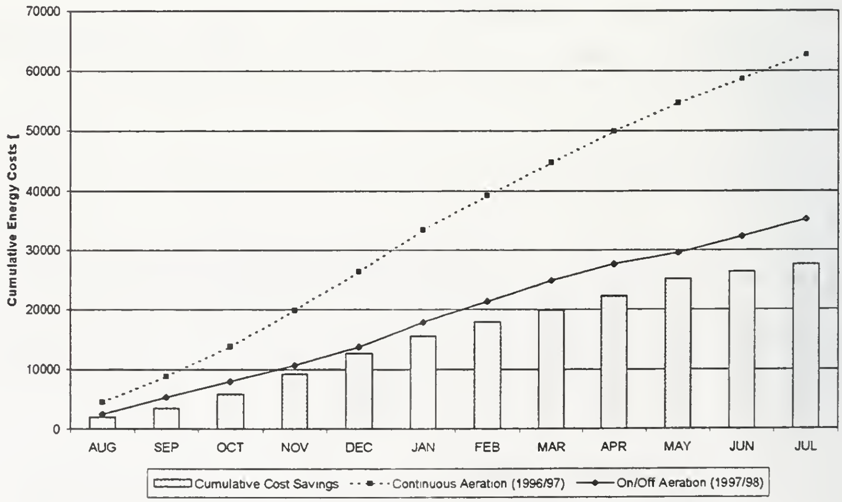


Figure A3-3 Cumulative energy cost and cost savings at Elmvale WPCP.

Plant Description

Paris WPCP is an extended aeration (EA) activated sludge plant (ASP) with a design flow of 7.1 MLD. The plant consists of two parallel trains, with each train consisting of two square aeration tanks and two rectangular final clarifiers. The plant can be operated in step-feed mode and the flow-split to the two trains can also be adjusted. Returned activated sludge (RAS) recycle is combined with the raw wastewater in the channel leading to the first two aeration tanks. The final effluent is chlorinated in a chlorine contact chamber before discharging directly into the Grand River.

Aeration System Each of the four aeration tanks has one 25 HP mechanical surface aerator. The aerators are equipped with mechanical timers. The plant does not have online DO monitoring or control capability. DO levels in the aeration tanks are measured manually using a YSI probe/meter.

Operation Prior to On/Off Aeration The plant was operating in continuous aeration mode with an ADF of 3.3 MLD, or about 46% of design flow. This corresponded to an HRT of 47 h. The plant receives mainly residential wastewater but it also receives a highly variable industrial load from a nearby poultry processing plant which results in low (or limiting) DO levels in the aeration tanks. Low DO levels are also experienced during the normal high loading periods of the day. Although the plant is not required to nitrify, it achieved almost complete nitrification year round. Historical operating data indicated that the regulated effluent parameters (BOD, TSS, TP) were below their discharge limits. The average power consumption for the entire plant was 1717 kWh/d and the specific power usage was 0.52 kWh/m3 of wastewater flow. This power usage is relatively low compared to typical values for the size and type of plant.

Implementing On/Off Aeration

Screening Following a site visit and a review of the plant's design and operating data, Paris WPCP was selected for implementing on/off aeration for the reasons listed below.

1.	Plant/Capacity	Extended aeration ASP operating at about 50% of design capacity
2.	Aeration	Mechanical surface aerators One 25 HP aerator in each of four aeration tanks Aerators equipped with timers Experienced DO limiting conditions at times.

3.	Mixing	On/off trials showed that residual turbulence and in-flow mixing were sufficient to keep the mixed liquor solids in suspensions for over 30 min with the aerator turned off.
4.	Wastewater	Mainly municipal wastewater Periodic high industrial load from a poultry processing plant.
5.	Nitrification	Achieving almost complete nitrification year round
6.	Effluent limits	No effluent ammonia limit
7.	Energy	Specific power usage of 0.52 kWh/m3 Relatively low for the size and type of plant
8.	Retrofit Cost	Cost of purchasing and installing soft start switches on aerators
9.	Savings	Because of the low DO conditions at the plant and the relatively low specific power usage, the aeration energy saving expected was about 20%. This is based on shutting off the aerators in the first two tanks 50 % of the time. The total energy saving was expected to be about 10 % assuming that the aeration system accounted for about half the total energy usage.

Retrofit/Operational Changes The retrofit and operational changes made as part of implementing on/off aeration are as follows:

1. SRT Control
   - A sludge mass control program was implemented in Fall 1997, about 2-3 months prior to starting on/off aeration. The necessary process control tests were performed 3-4 times per week.
2. Cycling Aerators
   - Soft start switches for the aerators were purchased during Fall 1997 and installed in early winter. The aerators were already equipped with timers.
   - The operator has the flexibility to change the cycle times and suspend on/off aeration at anytime.
   - On/off aeration operation was initiated in February 1998 by cycling the aerators in the first two aeration tanks at 30min on / 30min off.
3. Mixing
   - No retrofit was made for mixing. Mixing was provided by the in-

flows and residual turbulence in the tank during the off cycle.

4. Other Changes - *No other changes were made at the plant.*

Optimization The following changes were made to optimize the plant's performance during on/off aeration.

1. Cycle Times
   - On/off cycle times were set at 30min on/30min off for each aerator in the first two aeration tanks. The cycle times were maintained at these values for six months (Feb. – July 1998).
   - The process was switched back to continuous aeration mode in August 1998 after the organic load to the plant had increased significantly. This resulted in limiting DO conditions in the aeration tanks and a reduction in nitrification efficiency.

2. Target SRT
   - The target SRT was adjusted based on seasonal variations in wastewater temperature, effluent ammonia concentrations, and the operator's experience.

3. Other Parameters
   - *Due to the limited aeration capacity, the plant had no means of handling the low DO levels in the aeration tanks during the periods of high industrial loadings. The only option was to return to continuous aeration mode.*

Results and Discussion

The SRT control program was implemented in the fall of 1997, the plant was retrofitted in late fall, and on/off aeration was initiated in February 1998. The plant's operation and performance were closely monitored and evaluated over an 8 months period (February – September 1998) as part of this study. The monitoring data from this period are compared to the data from the corresponding period from the previous year (February - September 1997), when the plant was operating in continuous aeration mode. The average operating and performance data for the periods before and with on/off aeration are summarized in **Tables A4-1** and **A4-2**, and highlights of the results are presented below:

- The plant was operated in on/off aeration mode for about 6 months (February – July 1998). It was returned to continuous aeration in August 1998 after experiencing severely low DO levels in the aeration tanks as a result of increased organic loading. This was believed to come from a nearby poultry processing plant.

- Prior to starting on/off operation in February 1998 the plant was nitrifying only partially. After starting on/off operation, the plant began losing nitrification and lost nitrification completely by March 1998 (see **Figure A4-1**). With the increased in mixed liquor temperature in April, the plant started to nitrify again in the spring. However a significant increased in organic loading in July 1998 resulted in the plant starting to lose nitrification again and the operator returned the plant to continuous aeration mode.
- The plant was operating in on/off aeration mode while it was not nitrifying during the winter. No negative effect was observed for the regulated effluent parameters (cBOD, TSS and TP). As expected, there was increased effluent ammonia-N and TKN concentrations during this period (see **Figure A4-1**).
- The plant was operated with comparable ADF and hence HRT, during the periods before and with on/off aeration (**Table A4-1**).
- During on/off aeration the aerator in the first tank in each train was cycled at 30min on/30min off. This corresponded to a 25% reduction in the aerobic HRT (i.e., two of the four aerators were off 50% of the time).
- The plant continued to produce a good quality effluent with respect to the regulated discharge parameters. The average concentrations of the regulated effluent parameters (cBOD, TSS, TP) before and after implementing on/off aeration were practically unchanged.
- The average effluent NH3-N during on/off aeration (4.7 mg/L) was significantly higher than before on/off operation (1.8 mg/L). Data on effluent NO3-N or TN concentrations were not available for the period before the study. The average effluent NO3-N and TN during on/off operation was 7 and 11 mg/L respectively.
- Based the plant's total energy usage the energy saving due to on/off aeration is about 13%. This corresponds to an annual energy cost savings of approximately $5600.
- The cost of implementing on/off aeration (installing soft-start switches) was about $8200. Thus the payback time would have been about 1.5 year if the plant could operate in on/off aeration mode all year. However this was not possible because of the highly variable loading the plant was experiencing which resulted in limiting DO conditions. The energy cost and cost savings are plotted in **Figure A4-2**.

Table A4-1 Average operating parameters before and with on/off aspiration

Operating Parameters	ADF	HRT	On/Off CycleTime	Aeration ON	Energy Usage	Energy Cost
	MLD	H	Min/min	%	MWh/yr	$/yr
Before On/Off	3.3	47	-		627	42,860
With On/Off	3.4	46	30/30	75	545[b]	37,290[b]
Annual Savings					**13 %**[a]	**$5600**[b]

(c) Percent energy and cost savings were calculated by comparing the energy usage and cost for the periods Feb – Jul 97 (continuous aeration) and Feb – Jul 98 (on/off aeration).

(d) The annual energy usage, energy cost and cost savings with on/off aeration were estimated using the percent savings with on/off aeration (13%) and the annual energy usage (627 MWh/yr) and energy cost ($42,860/yr) with continuous aeration (Feb 97 – Jan 98).

Table A4-2 Average effluent parameters before and with on/off aeration

Parameters	CBOD	TSS	TP	NH3-N	TKN	TN
			mg/L			
Aeration Influent[a]	139	207	5.7	N/A	42	N/A
Final Effluent						
Before On/Off[b]	3	5	0.6	1.8	N/A	N/A
With On/Off[c]	8	11	0.3	4.7	8	11

(d) Average primary effluent concentrations (Feb 97 – Jul 98)

(e) Average final effluent concentrations with continuous aeration (Feb 97 – Jan 98)

(f) Average final effluent concentrations with on/off aeration (Feb 98 – Jul 98)

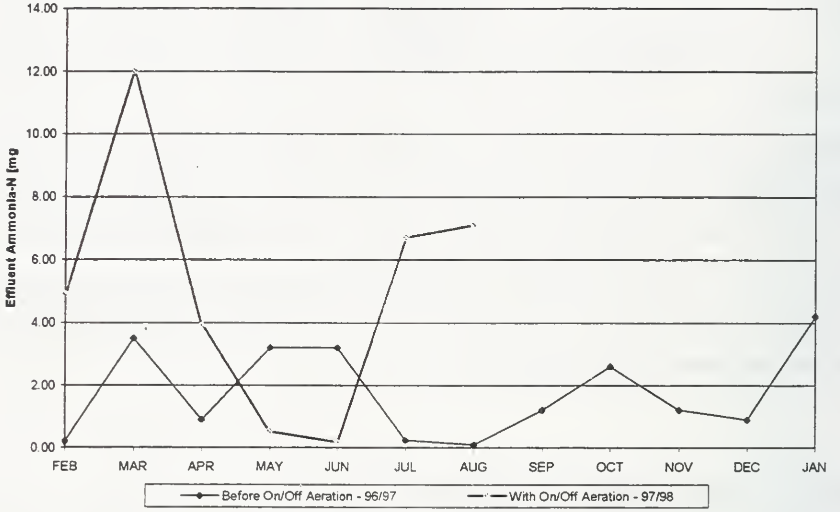


Figure A4-1 Effluent ammonia-N concentration before and with on/off aeration

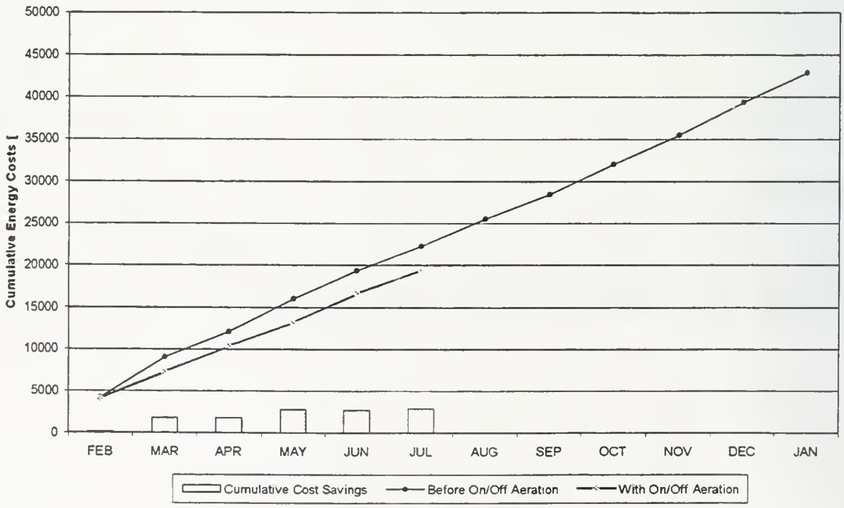


Figure A4-2 Cumulative energy cost and cost savings at Paris WPCP.

Table 12. Princess Margaret Blvd Statistics Summary 1997-1998

Appendix B

Screening Candidate Plants:

Site Visit Information Sheet

Table 12. Princess Margaret Blvd Statistics Summary 1997-1998

Site Visit Information Sheet

General Information

Plant Name:	______	Authority:	______
Superintendent:	______	Location:	______
Phone:	______	Region:	______
Fax:	______	AOC or RAP:	______

Plant Information

Plant Type	______	Nitrifying	______
Design Flow	______	N - Monitoring	______
Average Flow	______	DO - Monitroing	______
Trains	______	DO - Control	______
Primary	______	Co-Thickening	______
Aeration Tank	______	HRT	______
Final Clarifier	______	SRT	______

Sludge Handling ______

Comments: ______

Aeration & Mixing Systems

Aeration	______	Mixing	______
Type of Aerator	______	Type of Mixer	______
Aeration Control	______	Mixer Control	______

Comments: ______

Wastewater Information

	Influent	Effluent	Discharge Limits
BOD5			
TSS			
TP			
TKN/NH3-N			
TN			
Other			

Industrial ______________________________

Wet Weather ______________________________

Retrofit Needs

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

Other Information

Future Expansion ______________________________

Energy Monitoring ______________________________

Analytical/Monitoring ______________________________

Record Keeping ______________________________

General Comments ______________________________

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